MASTER

Physique fondamentale et applications

SCIENCES SORBONNE UNIVERSITÉ

M1 - Fiche descriptive de l'UE : Physics of Navigation Satellite Systems

Année 2024-2025

Intitulé de l'UE : Physics of Navigation Satellite Systems	**Code Apogée UE : MU4PY218** **Nombre d'ECTS : 3**
Responsable de l'UE :	Nom : Philip TUCKEY Adresse : SYRTE, Observatoire de Paris, 77 avenue Denfert-Rochereau, Paris 14 Tél : 01 40 51 22 46 Courriel : philip.tuckey@obspm.fr
Volumes horaires globaux :	30h.
Période où l'enseignement est proposé :	S2, janvier à mars. Cette UE est commune avec le Master de l'Observatoire de Paris ; l'enseignement commence normalement 1 semaine avant les autres UE du Master de Sorbonne Université. *2nd term, January to March. This course is shared with the Paris Observatory Master; the teaching usually starts 1 week earlier than the other Sorbonne University courses.*
Localisation des enseignements :	Observatoire de Paris, 77 avenue Denfert-Rochereau, Paris 14
Objectifs :	*Ce cours est enseigné en anglais. This course is taught in English.* This course explores the wide-ranging science and engineering topics which underpin the design and utilisation of positioning systems based on satellite constellations, in particular the Global Navigation Satellite Systems: GPS, GLONASS, Galileo, Beidou. These topics include historical positioning and navigation methods, mapping techniques, atomic clocks, orbital mechanics, general relativity, atmospheric physics, radiocommunication and signal modulation. Some of these topics are more generally relevant for space missions. The lesson time is shared between conventional (short) presentations of the course material and a variety of student activities such as document studies, problem-solving, short presentations, with an emphasis on collaborative work in groups.
Pré requis :	Classical mechanics and basic notions of special relativity and quantum mechanics typically taught at undergraduate level.
Thèmes abordés / Notions et contenus :	• Metrology of positioning: different methods available for positioning on Earth; analysis of positioning requirements for a given application; design of a positioning system that can satisfy such requirements. • Orbits: physics of orbits and Kepler's laws; types of orbits around the Earth; orbit parametrization, Keplerian elements, perturbations... • Atomic clocks: historical development of clocks; physics (quantum mechanics) of atomic clocks such as atomic energy levels, Schrödinger's equation, Rabi/Ramsey interrogation, analysis of interference signal in clocks; different types of atomic clocks. • Time and frequency metrology of clocks: basic notions of uncertainty, stability and accuracy; Allan variance and power spectral density; systematic effects, in particular in atomic clocks. • Relativistic chronometry: reference systems; space-time diagram and related concepts such as world line, light cone, proper time, space-time interval, simultaneity conventions...; calculation of coordinate time and proper time for simple trajectories. • Geodesy and geographic maps: notion of ellipsoid, geoid and map projection; conversion between geographic coordinates and Cartesian coordinates; classes of map projections. • Physics of the atmosphere: influence of different atmospheric layers on GNSS signal propagation, in particular the ionosphere and troposphere; modelling of dispersion; tropospheric and ionospheric delays, orders of magnitude; rejection of ionospheric effects; correction of tropospheric effects. • Physics of signals: general concepts such as pseudo-random code, carrier and modulation; GNSS signals, structure, codes (C/A, P and navigation message),

BPSIE	frequency bands, separation of signals from different satellites, RINEX file format; measurement of pseudo-distance. • GNSS data analysis: use of GNSS-Laboratory (gLab) for treating positioning data and studying the various corrections applied.
Compétences attendues à la fin de l'UE :	• describe different methods of positioning on the Earth's surface • analyse the positioning needs for a global navigation system • define the orbital elements which describe an orbit and use the kinematical and dynamical orbital equations to calculate the properties of orbits • list the different types of satellite orbits, describe their characteristics and identify the appropriate type of orbit for a given application • describe the basic principles of clocks including atomic clocks • solve Schrödinger's equation describing Rabi-Ramsey interrogation of an atomic clock • define statistical and systematic measurement error and uncertainty in general and their characteristics for clocks • explain the basic notions and tools of special and general relativity • define the reference frames used in the vicinity of the Earth and in the Solar system • calculate and compare the proper time measured by clocks in different positions on Earth and in orbit • define the concepts reference ellipsoid, horizontal and vertical coordinates, geoid used in mapping • calculate geographical coordinates from cartesian coordinates • describe the main classes of map projections • describe the properties of the layers of the atmosphere influencing GNSS signals: ionosphere and troposphere • model the physical mechanisms responsible for signal dispersion, estimate the order of magnitude of the ionospheric and tropospheric delays and explain how to correct or reject them • understand and explain the structure and typical characteristics of GNSS signals: navigation message, PRN code, carrier wave and modulation • define the navigation equations used for GNSS positioning • describe the data collected by GNSS receivers and use gLAB to analyse that data to calculate the position and the values of the physical effects included in the calculation
Ouvrages de référence :	ESA GNSS Data Processing Book Volumes 1 and 2, available at: https://gssc.esa.int/navipedia/index.php/GNSS:Tools Specific reference documents are provided for each lesson.
Modalités d'évaluation :	• participation in the student work activities during the lessons • 3 homework exercises • the final exam is replaced by a project, carried out in groups and evaluated on the basis of a shared oral presentation (one per group), given during the final lesson. The project assessment is based on the presentation slides (no other written report is required), the oral presentation itself and answers to questions.
Barèmes (Apogée) :	20% for the work in class, 30% for the homework exercises (10% each), 50% for the final project. This UE does not have a second session.