Summarized Content of Courses

- *Although all the courses were certainly important and essential for my formation as physicist and scientist, highlighted courses with red color are considered by me as the more relevant for my formation in astrophysics and their contents should be reviewed more detailed.*
- *Courses of the first five terms are briefly described because they are standard in many undergraduate programs of engineering and science.*

Note: One credit equals: 15 theoretical hours per term. From 45 to 60 hours for laboratories per term.

FIRST TERM 2007

(4 credits) **Algebra and Trigonometry:** Real and complex numbers. Equations and Inequations. Functions. Analytic Trigonometry.

(4 credits) **General Anthropology:** Introduction to basic concepts of anthropology.

(4 credits) **Euclidean Geometry:** Geometric figures. Congruence of triangles. Triangular inequality. Circumferences. Plane figures. Euclid's postulates.

(4 credits) **Physics Fundamentals:** Introduction to physics from an historical approach. Newtonian mechanics. Electromagnetism. Thermodynamics. Modern Physics.

(4 credits) **Calculus Fundamentals:** Basic notions of calculus. Limit and continuity. Functions and relations. Logic. Derivatives and antiderivatives.

(4 credits) **Spanish Language I:** Basic contents in spanish language.

SECOND TERM 2007

(4 credits) **Calculus I:** Limit and continuity of real functions. Derivatives and antiderivatives. Applications of derivatives. Optimization of functions. Integrals of basic functions. Applications of integrals in physics.

(4 credits) **Computers in Physics:** Introduction to Unix and Linux systems. Logic programming. Pseudocode. Compilers. Programming in C and C++ languages. Basic applications to physics and mathematics. Gnuplot.

(4 credits) **Physics I:** Newtonian mechanic. Kinematics and dynamics. Work and energy. Linear momentum and energy conservation laws. Rigid body. Angular momentum conservation law. Introduction to fluid mechanics and thermodynamics.

(4 credits) **Psychology and Psychoanalysis Fundamentals:** Introduction to basic concepts of psychology and psychoanalysis.

(4 credits) **Vector Geometry:** Vectors. Applications of vectors. Conic curves. Parametric surfaces. System of linear equations.

(1 credit) **Physics I Laboratory:** Laboratory experiences related to the contents of Physics I.

FIRST TERM 2008

(4 credits) **Linear Algebra:** Vectorial spaces. Linear transformations. Matrices and determinants. Characteristic polynomials. Canonical forms. Dual spaces. Intern product. Bilinear and quadratic forms. Complex vectorial spaces.

(4 credits) **Calculus II:** Indeterminate forms and Improper integrals. Successions and infinite series. Plane curves, parametric equations and polar coordinates. Vectorial functions in the plane and the space.

(4 credits) **Physics II:** Oscillations. Gravitational interaction. Electric interaction. Electrostatic fields. Circuits of direct current. Magnetic interaction. Ampere's law. Time-dependent electromagnetic fields.

(1 credit) **Physics II Laboratory:** Laboratory experiences related to the contents of Physics II.

(3 credits) **Seminar I:** Star to get involved with scientific lectures and articles in english language. Practice english through oral presentations and discussions about topics in general physics.

SECOND TERM 2008

(4 credits) **Calculus III:** Limit and continuity of multivariate functions. Multivariate differentiation and high order derivative operators. Multivariate integration and high order integrals. Vectorial calculus, Green theorem, Stokes theorem, Gauss theorem. Parameterized 3D surfaces. Applications.

(4 credits) **Ordinary Differential Equations:** Differential equations of first order. Different types and methods of solutions. Applications of differential equations of first order. Differential equations of high order. Linear equations with constant coefficients. Non-homogeneous differential equations. Series solutions. Laplace and Fourier transforms. System of differential equations. Autonomous systems and stability.

(4 credits) **Physics III:** Wavelike movement and elastic waves. Electromagnetic waves. Reflection and refraction. Polarization. Interference and diffraction.

(4 credits) **Mathematical Physics I:** Complex numbers, definition, geometric and polar representations. Functions of a complex variable, limit and continuity, derivatives, analytic functions, Cauchy-Riemann conditions. Elemental functions. Integrals of functions of a complex variable. Complex power series. Method of residuous. Conformal maps and applications. Variational methods. Statistics and probability.

(1 credit) **Physics III Laboratory:** Laboratory experiences related to the contents of Physics III.

FIRST TERM 2009

(4 credits) **Mathematical Physics II:** Vectorial calculus in generalized coordinates. Different types of multivariable differential equations, parabolic equations, hyperbolic equations, parabolic equations. Green's functions. Applications to physics, multidimensional wave equations, Schrodinger equation, heat equation, Poisson equation.

(4 credits) **Modern Physics:** Introduction to special and general relativity. Basic concepts of quantum mechanics, Schrodinger equation, 1D potential wells. Introduction to particle physics and state solid physics.

(4 credits) **Astrophysics Fundamental:** Introduction to main topics in modern astrophysics. Stellar astrophysics. Planetary astrophysics. Galactic and extragalactic astrophysics. Cosmology.

(1 credit) **Modern Physics Laboratory:** Different laboratory experiences related to modern physics. Millikan experiment. Black body experiment. Franck-Hertz experiment. Photoelectric experiment. Cosmic radiation experiment. X-ray diffraction experiment. Charge-Mass relation experiment.

(4 credits) **Classical Mechanics:** Mechanics of a system of particles. D'alembert principle and Lagrange equations. Variational principle and Hamilton's principle. The central force problem. Small oscillations. Hamiltonian formalism of classical mechanics. Lagrangian formalism of classical mechanics. The principle of least action. Canonical transformation. Hamilton-Jacobi theory and action-angle variables.

(4 credits) **Thermodynamics:** Introduction and basic concepts of thermodynamics. Energy and the first law of thermodynamics. The second law and entropy. General relations of thermodynamics, enthalpy, Legendre relations, Maxwell's relations. Thermodynamics of phase changes. Introduction to non-equilibrium thermodynamics.

SECOND TERM 2009

(4 credits) **Electromagnetism I:** Electrostatic in vacuum, Coulomb's law, Green's functions, method of images, multipoles. Magnetostatic in vacuum, Lorentz force, magnetic multipoles, magnetic energy. Maxwell equations, law of conservation of charge, Lenz's and Faraday's laws, Ampere-Maxwell law, potentials, electromagnetic waves. Classic theory of radiation.

(4 credits) **Mathematical Physics III:** Finite groups, symmetric group, Lagrange theorem, Kronecker product, group representation, character tables, applications. Continuous groups, Lie group, Lie algebra, tensors, O(3), SO(3), SU(2), SU(3). Lorentz and Poincare groups, pseudo orthogonal group O(p,q), SL(2, C), supersymmetric algebras.

(4 credits) **Subatomic Physics:** Natural units. Relativistic notation. Forces of nature. Dirac notation. The standard model. Experimental facts in subatomic physics, detectors. The Higgs mechanism. Cross sections, decay widths and lifetimes.

(4 credits) **Computational Physics and Astrophysics:** Introduction to scientific computation. Python, C and C++ languages. Scientific libraries, gsl, numpy, scipy, linalg. Software and graphic libraries, Gnuplot, Matplotlib. Three different projects through the course: computation of the mechanical internal structure of rocky planets. Variational numerical method to compute hydrogenoid states. Basic simulation of a self-gravitating fluid based upon SPH (Smoothed Particle Hydrodynamics) scheme.

(4 credits) **Quantum Mechanics I:** Operator algebra. Dirac notation. Basic postulates of quantum mechanics. 1D, 2D and 3D potential wells. Free fall potential. Harmonic oscillator, creation and annihilation operators, coherent evolution of wave packets. Hydrogen atom, angular momentum operator, parabolic coordinates.

(4 credits) **Chaos Dynamics and Nonlinear Dynamics:** Basic concepts of nonlinear dynamics. Bifurcations. Flows on the circle. Linear systems. Phase plane. Limit cycles. Lorenz equations. One dimensional maps. Hamiltonian chaos. *Final project:* my final project in this course was related to hamiltonian chaos in analytic potentials of galaxies. A result of this project is the next code to simulate galaxies with analytic potentials (https://github.com/sbustamante/Galaxy).

FIRST TERM 2010

(4 credits) **Electromagnetism II:** Macroscopic electrodynamics, electric and magnetic properties of matter. Conductivity, dielectric materials, plasmas, diamagnetism, ferromagnetism, antiferromagnetism, paramagnetism. Polarization of matter. Constitutive relations. Maxwell's equation and electromagnetic waves in mediums. Dispersion relations. Reflexion and refraction in mediums. Waveguide and resonant cavities. Cherenkov radiation. Applications, negative refraction index and metamaterials, optical transformations in mediums.

(4 credits) **Statistical Physics:** Basic concepts of statistical physics, macroscopic and microscopic states, number of microstates, classical ideal gas, entropy and Gibbs paradox. Elements of Ensemble theory. The microcanonical ensemble. Applications of the microcanonical ensemble. The canonical ensemble. Applications of the canonical ensemble. The grand canonical ensemble. Applications of the grand canonical ensemble. Quantum statistics and applications, ideal Bose systems, ideal Fermi systems. Introduction to statistical mechanics of interacting systems.

(4 credits) **Quantum Mechanics II:** Fundamentals concepts. Schrodinger and Heisenberg pictures. Time evolution, Schrodinger equation, evolution operator. Theory of angular momentum, orbital angular momentum, spin 1/2 systems, finite rotations, euler rotations, density operator and mixes ensembles. Symmetry in quantum mechanics. Perturbation theory in quantum mechanics, time-independent and time-dependent schemes. Scattering theory. Variational method. Formalism of identical particles, second quantization.

(4 credits) **Relativity:** Origin of relativity from an historical perspective. Properties of space-time. Special relativity. Dynamics in special relativity. Minkowski space. Tensorial algebra. Tensors in special relativity. Covariant electrodynamics. Conservations laws. General relativity, metrics, geodesics, Christopher symbols, curved spaces, Riemann curvature tensor. General coordinate transformations. Einstein field equations. Applications: Schwarzschild metric, Friedmann equations, precession of the perihelion of Mercury.

(2 credits) **Seminar II:** Course oriented to research in some topic of interest by the student. The chosen topic was fundamentals of quantum mechanics. Specific topics: Uncertainty principle and its implications. Quantum entanglement. Cat states. Quantum decoherence. Bell's theorem and EPR paradox. Quantum interference of a single photon system.

SECOND TERM 2010

Term cancelled for all the undergraduate programs of the University because of the anomalous situation produced by student protests.

FIRST TERM 2011

(4 credits) **Atomic and Molecular Physics:** One-electron atoms, bound and free states, hydrogenoid atoms. Interaction of one-electron atom and electromagnetic radiation, transition rates, dipole approximation, selection rules, the photoelectric effect. Interaction of one-electron atom and the quantum electromagnetic field, Rabi model, Jaynes-Cummings model. Fine and hyperfine structures and interaction with external electric and magnetic field, Zeeman effect, Stark effect, Lamb shift. Two-electron atoms, Schrodinger equation for two-electron systems. Many-electron atoms, Thomas-Fermi model, Hartree-Fock model. Interaction of many-electron atoms with electromagnetic fields. Molecular structure.

(4 credits) **Relativistic Quantum Mechanics:** Classical field theory, Lagrangian formulation, global gauge invariance, relativistic notation, vector field Lagrangian, Schrodinger equation with electromagnetic fields, Proca equation, Klein-Gordon equation, Dirac's action. Quantum electrodynamics. Quantum Chromodynamics, Standard model Lagrangian. Spontaneous symmetry breaking. Computational QFT. Second quantization of the Klein-Gordon field and second quantization of fermions and bosons. S-matrix. Two body decays. Feynman rules.

(3 credits) **Seminar III:** Course oriented to start researching in the chosen topic for the undergraduate thesis of the student. The chosen topic was cosmology. Topics: basic concepts of cosmology. Cosmological principle. Metrics of curved spaces. Friedmann equations. The expanding universe. Power spectrum and initial conditions. Linear regime of structure formation, Newtonian approximation, Jeans instability, equation of evolution of Fourier modes of the density field and peculiar velocity field. Zeldovich approximation.

(4 credits) **Dynamic Systems II:** Introduction and basic concepts. Nonlinear tools. Phase space method. Determinism and predictability. Lyapunov exponent. Self-similarity, dimensions. Nonlinear phenomenons. Embedding methods. Invariants, entropies, relations between invariants. Chaos control. Advanced topics in hamiltonian chaos, Poincare maps. Final project: my final project of this course was a continuation of the project of *Chaos Dynamics and Nonlinear Dynamics*. It was made an analysis of the dynamical effect of bars and spiral arms, introduced as perturbations, on cylindrically symmetric potentials.

(4 credits) **Quantum Theory of Radiation:** Introduction and basic concepts. Field quantization, quantization of a single-mode field, quantum fluctuations, quadrature operators of a single-mode field, multipole fields, thermal states, vacuum fluctuations, quantum phase. Coherent states, eigenstates of the annihilation operator, wave packets and time evolution, density operators and phase-space probability distributions. Emission and absorption of radiation by atoms, atom-field interactions, the Rabi model, the Jaynes-Cummings model, dressed states, extensions of the Jaynes-Cummings model, von Neumann entropy. Nonclassical light, quadrature squeezing, squeezed light, cat states. Applications, interferometers, beam splitter, quantum Eraser, cavity QED, entanglement states.

SECOND TERM 2011

(4 credits) **Solid State Physics:** Electronic states in solids, adiabatic approximation, Hartree-Fock approximation, Bloch's theorem, Wannier functions, spin-orbit interaction in solids, K.P. method. Dynamic of electrons in solids, effects of impurities in solids, electrons in crystals, tunneling between bands assisted by external electric and magnetic fields, excitons in solids, Wannier excitons. Dynamic of the crystalline red, classical and quantum harmonic approximation for oscillations in the crystalline red, annihilation and creation operators of photons, photon as bosons, photon-electron interaction. Transport phenomena, Onsager relations, thermoelectric effects, quantum description of the electric conductivity, magnetotransport effects. Integer and fractional quantum Hall effect.

(4 credits) **Planetary Science:** Planetary physics and processes, planetary dynamics, planetary interior, planetary surfaces, magnetosphere and interplanetary medium, planetary rings. Solar system, introduction, planets of the solar system, planetary atmospheres, planetary moons. Extrasolar planets and astrobiology, planetary formation, exoplanets, habitable zone, possibility of life.

(4 credits) **Continuum Mechanics Fundamentals:** Continuous and discrete mediums, models of material bodies. Fundamental equations of elasticity theory, Hooke's law, deformation tensor, traction, compression and shear tensor, thermodynamics of deformations, elastic properties of crystals. Equilibrium of bars and plates, deformation of beams, torsion and flexion in bars, energy of deformed bars, curved plates and shells, stability of elastic systems. Elastic waves in mediums, vibration in bars and plates, anharmonic vibrations. Dislocations. Thermal conduction and viscosity in solids. Fluids, Viscosity, Newtonian and Stokes fluids, Navier Stokes equation, Helmholtz equation.

(4 credits) **Quantum Field Theory:** Introduction, canonical formalism and procedure for the quantization of particles, symmetries and conservation laws. The Klein-Gordon field, charged scalar field, Feynman propagator for Klein-Gordon fields. Dirac field, Dirac theory, quantization of a Dirac field, Feynman propagator for Dirac fields. Electromagnetic field, quantization of the Coulomb gauge, covariant quantization, Feynman propagator of the electromagnetic field. Interacting fields and perturbation theory, vacuum self-energy, S-matrix, Wick's theorem, Feynman rules. Path integrals and functional calculus, formulation of the quantum mechanics through path integrals, generatriz function for scalar and spin fields. Renormalization, dimensional analysis, counterterms and renormalization of QED, anomalous magnetic moment of the electron, asymptotic behaviour of QED.

FIRST TERM 2012

(2 credits) **Professional Ethics:** Compulsory course for all the majors.

(3 credits) **Advanced Experimentation:** Advance experiments in modern physics. Hall effect. Synthesis and characterization of iron oxides. Mossbauer spectroscopy. Photolithography of thin films. Spectrophotometer of optic fiber and applications. Free final project: the final project was related to the processing of audio signal of musical instruments in order to decompose melodies of differents instruments played at the same time through Fourier analysis and computational tools developed in python.

(0 credits) **Constitutional and Civic Formation:** Compulsory course for all the majors.

(4 credits) **Guided Reading:** Course dedicated to do all the bibliographic review for the thesis project.

SECOND TERM 2012

(5 credits) **Thesis: Title:** the place of the milky way and andromeda in the cosmic web **Description:** This study is aimed to characterize the local environment of Local Group (LG)-like systems from dark matter simulations of the large-scale universe. Using two different types of simulations, an unconstrained simulation (Bolshoi project) and a set of constrained simulations (CLUES project), it is first constructed a LG-like sample based upon observational constrains on the kinematic properties and isolation criteria of the real LG, along with the results of the CLUES simulations. By using a tensorial scheme based upon the peculiar velocity field of the dark matter, the V-web scheme, it is classified the local environment of systems in each simulation. Finally, it has been found that LG-like systems lies preferentially in sheet-like regions, furthermore a significant environmental bias for the total mass and the specific energy. No correlations have been found for the specific angular momentum and other studied properties.