

Academic Year/course: 2021/22

## 39133 - Chaos and Nonlinear Dynamic Systems

### Syllabus Information

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**Academic Year:** 2021/22

**Subject:** 39133 - Caos y sistemas dinámicos no lineales

**Faculty / School:** 100 - Facultad de Ciencias

**Degree:** 577 - Joint Program in Physics and Mathematics

**ECTS:** 5.0

**Year:** 3 and 4

**Semester:** Second semester

**Subject Type:** Optional

**Module:**

## 1. General information

### 1.1. Aims of the course

Non-linear science is a cross-disciplinary discipline with implications in all areas of science and engineering. The fundamental objective of the course is to provide the student with the basic and computational tools necessary for the study of nonlinear dynamic systems. Given a non-linear dynamic system we are interested in characterizing it properly according to its portrait of phases (fixed points, limit cycles, strange attractors ....) and study the possible bifurcations (static and dynamic phase transitions) that appear when the different parameters of interest are varied. This study will lead us to the presentation of three fundamental paradigms of the non-linear science; the phenomena of chaos, synchronization and nonlinear localization.

Along the course we will work with many different systems and in this way the second fundamental objective will be addressed: To provide to the student basic mechanisms and tools for the design of simple models of complex phenomena.

### 1.2. Context and importance of this course in the degree

This is an optative course that must be completed in the second semester of the third or fourth year of the degree. It wants to approach the student to the study of a number of problems in the frontier of physics that are usually alien to the core of physics studies. In this way, based on the knowledge obtained by the student along the previous semesters of the degree, the student will be able to address a large number of interesting problems in various disciplines. Such problems have not been studied previously either because of their complexity (the study of the non-linear pendulum as mechanical system for example) or because of its location outside the traditional trunk of the studies in physical (modeling of biophysical systems for example). Acquired knowledge will allow the student to approach the frontier of knowledge in the field of Statistical and Nonlinear Physics, one discipline of physics with great activity today.

### 1.3. Recommendations to take this course

It is recommended to have studied the courses of Mathematical Analysis, Differential Equations and Computational Physics. Likewise, it is recommended a continuous follow-up of the course with attendance to the classes and interaction with the faculty of the course.

## 2. Learning goals

### 2.1. Competences

Upon passing the course, the student will be more competent to:

- Analyze and understand nonlinear phenomena in various scientific fields.
- Master the tools of nonlinear science
- Develop and analyze non-linear dynamic models.
- Understand the paradigmatic phenomena in non-linear science: chaos, localization and synchronization.
- Simulate nonlinear dynamic systems

### 2.2. Learning goals

To pass this course the student must demonstrate the following results:

- Understands the singularity and importance of nonlinear dynamic systems.
- It is capable of analyzing a non-linear dynamic system.
- Knows the fundamental bifurcations characteristic of nonlinear dynamic systems.
- Understands and quantifies the phenomenon of chaos.
- Understands the basis of the synchronization phenomenon.
- Understands the phenomenon of non-linear localization.
- Recognize and model nonlinear phenomena

### 2.3. Importance of learning goals

The importance of the learning achieved is basically based on two considerations. On the one hand, the transversality of the course will introduce the student to numerous systems not only of physics, but also of biology, the chemistry or engineering likely to be addressed with the tools acquired. On the other hand the student will learn to make simple models of a diversity of natural phenomena.

We believe that the course Chaos and Nonlinear Dynamic Systems is a fundamental course for deepening in some of the most interesting problems in science today.

## 3. Assessment (1st and 2nd call)

### 3.1. Assessment tasks (description of tasks, marking system and assessment criteria)

The marking system is established from 0 (lower mark) to 10 (higher mark) points. The student needs a 5 to pass the course.

The student must demonstrate that he/she has achieved the expected learning outcomes through the following assessment activities:

a) Continuous evaluation of the student's learning by means of 5 short questionnaires on the different topics (1 to 5) of the course syllabus. These questionnaires will contain multiple-choice or true-false questions and are intended to assess the degree of understanding and application of the concepts and tools explained and used in class. These 5 activities will have the same weight and together contribute to 50% of the final grade. The minimum mark to pass this assessment must be 3.5 out of 10.

b) Realization and defense of an academic work. A list of works will be provided at the beginning of the course. The defense of the work will consist of a public presentation of 10 minutes per student plus answer to the questions raised. This activity contributes 50% of the final grade. The minimum grade to pass the activity must be 3.5 out of 10.

For those approved, the final grade (**NF**) will be calculated by renormalizing the student's average grade (**NP**) for the highest average grade achieved in the group (**NPmax**):

$$NF = 5 * [1 + (NP - 5) / (NPmax - 5)] \text{ (thus if } NP = 5 \text{ then } NF = 5, \text{ if } NP = NPmax \text{ then } NF = 10).$$

If NPmax is less than 9 then the given formula will be adopted using NPmax equal to 9.

#### Overcoming the course through a unique global test

This global test will consist of a written exam (50% of the final grade) and the evaluation of the work done and its public defense (50% of the final grade).

Students who have already defended the work are exempt from its presentation within the only global test.

## 4. Methodology, learning tasks, syllabus and resources

### 4.1. Methodological overview

The methodology followed in this course is oriented towards achievement of the learning objectives. A wide range of teaching and learning tasks are implemented, such as theory sessions, practice sessions, simulation practice sessions, and assignments.

### 4.2. Learning tasks

The course includes the following learning tasks:

- **Theory sessions:** basic theoretical contents and practical skills are presented in a combined way.
- **Practice sessions:** in these sessions, the students will have to solve problems in collaboration with other classmates and under the supervision of the teacher.
- **Simulation practice sessions:** students will become familiar with the notions of computational physics that are basic in the study of nonlinear dynamic systems.
- **Assignments:** the student will demonstrate that he is able to integrate the knowledge received in the resolution of a problem of nonlinear physics.

### 4.3. Syllabus

The course will address the following topics:

- Topic 0. Introduction.
- Topic 1. One-dimensional dynamical systems. Flows in the line, bifurcations, flows in the circle.
- Topic 2. Two-dimensional dynamical systems. Linear systems in the plane, phase plane, oscillations and limit cycles, bifurcations in the plane.
- Topic 3. Chaos. Lorenz equations, one-dimensional maps, fractals, strange attractors.
- Topic 4. Non-linear systems with many degrees of freedom and complex interactions. Introduction to the physics of complex networks. Kuramoto model and synchronisation in complex networks.
- Topic 5. Stochastic processes and nonlinear systems. Propagation phenomena in networks. Epidemic models in metapopulations.

### 4.4. Course planning and calendar

The course takes place during the second semester of the Physics degree.

Further information concerning the timetable, classroom, assessment dates and other details regarding this course, will be provided on the first day of class or please refer to the Faculty of Sciences website.

### 4.5. Bibliography and recommended resources

<http://psfunizar10.unizar.es/br13/egAsignaturas.php?codigo=39133>