Nonlinear Dynamics and Chaos

PHYMSCFUN12

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MSc in Fundamental Physics

Yachay Tech University - 2025

Contact:

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Tutoring schedule:

If you have questions on the material, my office hours are:

- **On Mondays:** 18:00 - 20:00
- **On Thursdays:** 18:00 - 20:00

Description of the MSc course

This graduate-level course provides a comprehensive computational exploration of nonlinear dynamics and chaos with a special focus on their application to fluid mechanics.

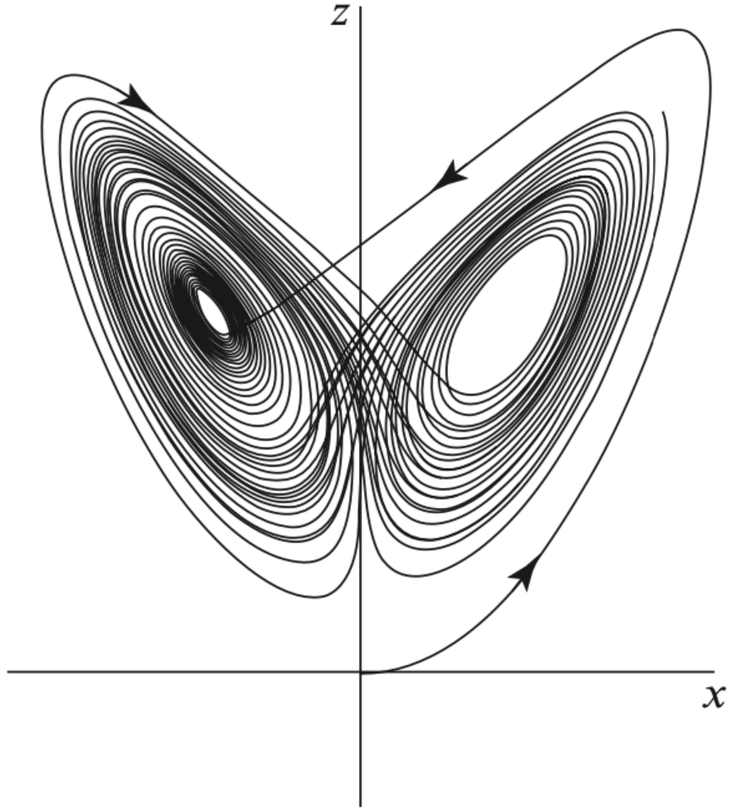
The MSc course has 2 parts:

PART I:

The first part of the course presents a strong foundation in the computational and mathematical tools necessary to study complex systems.

It includes Python programming sessions and the analysis of continuous and discrete dynamical systems.

It then delves into the geometric signatures of chaos by examining strange attractors, fractals and fractal dimensions.



Credits: Strogatz's book.

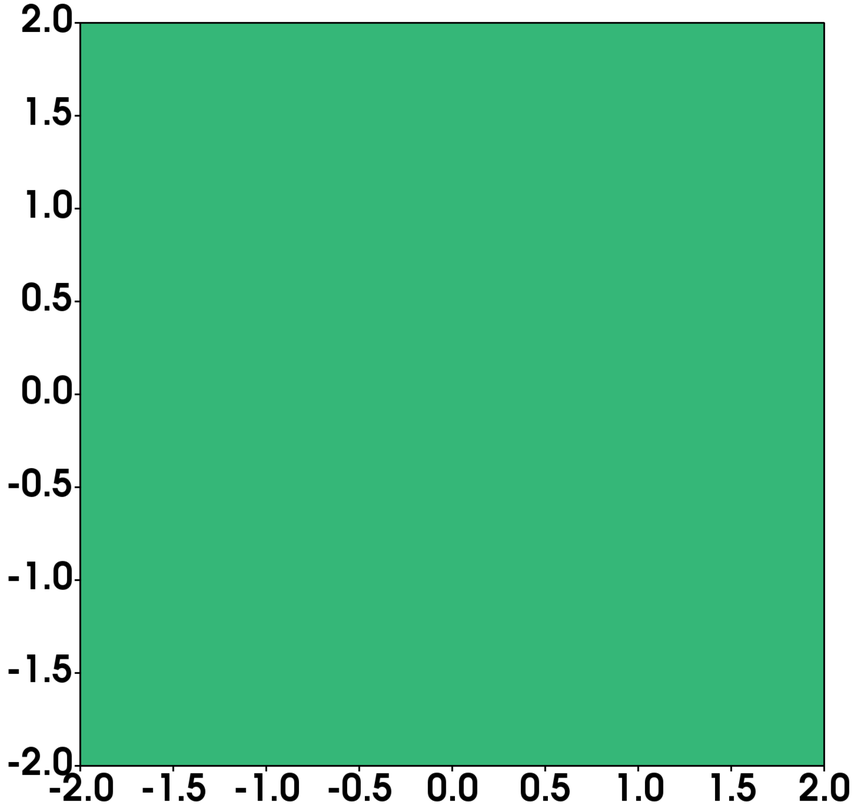
Description of the MSc course

PART II:

The second half of the course applies these concepts to the highly nonlinear field of fluid dynamics, starting with the **Navier-Stokes equations** and fundamental fluid phenomena like vorticity and boundary layers.

The course then dives into **turbulence**, where we will explore key theories like the **energy cascade** and discover how **fractals** are used to describe the intricate structures and chaotic mixing within turbulent flows.

This structure is designed to provide both the theoretical knowledge and the practical skills to analyse and understand complex, nonlinear phenomena in physics and engineering.



Credits: Myself

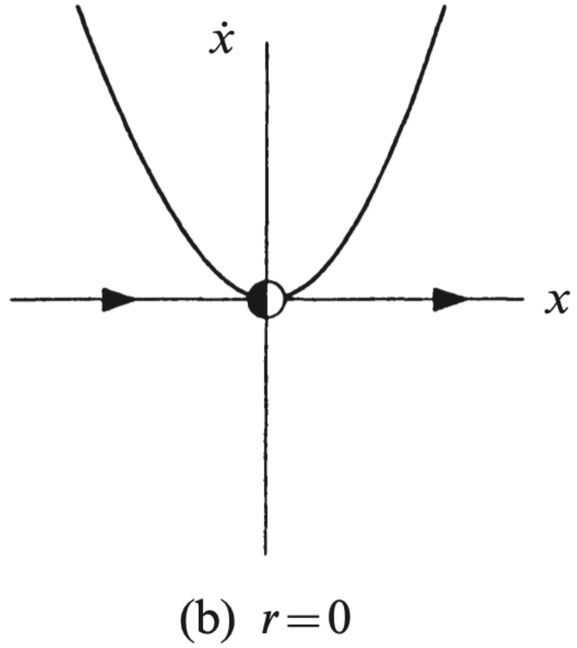
Learning Outcomes

You will learn techniques and concepts of nonlinear dynamics, which are widely applicable in diverse contexts and areas of physics and interdisciplinary applications.

Course Units

Unit 1: Computational Nonlinear Dynamics

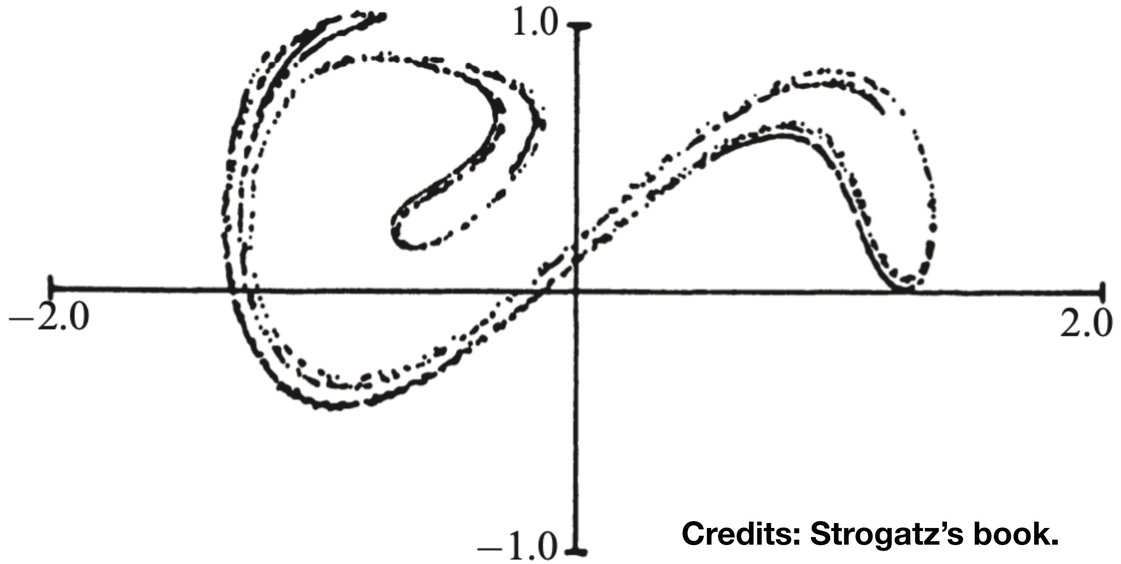
- Python and computational methods
- Software design for physics
- Continuous and discrete dynamical systems
- Bifurcations and transitions to chaos



Credits: Strogatz's book.

Unit 2: Fractals and Complex Systems

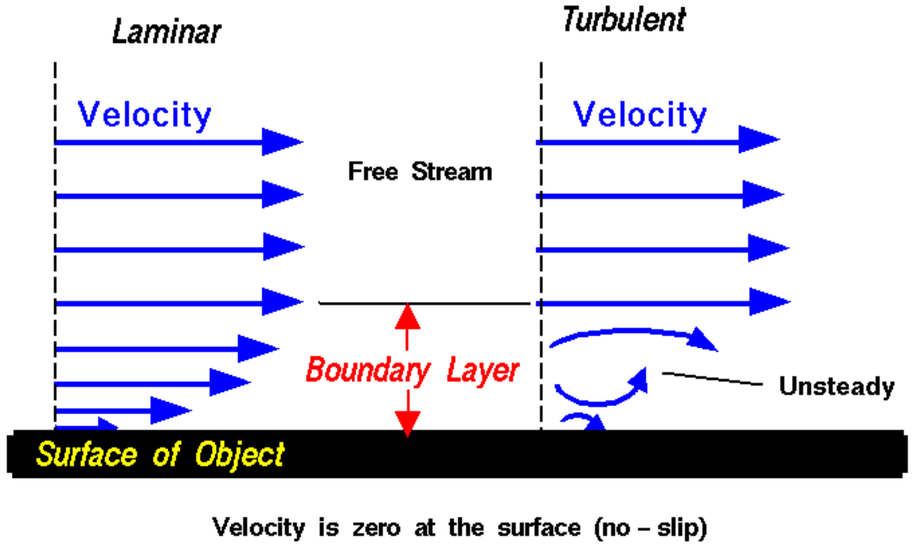
- Strange attractors
- Introduction to complex systems
- Fractal geometry and dimensions
- Fractal dimensions and multifractals



Credits: Strogatz's book.

Unit 3: Nonlinear Fluid Dynamics

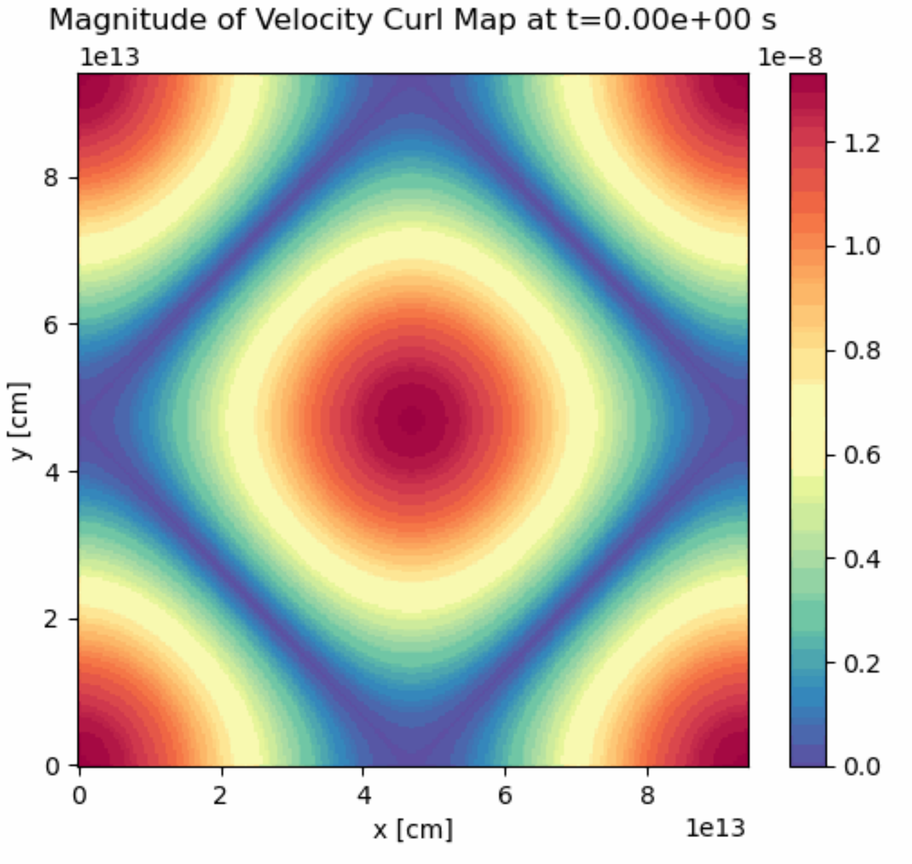
- Navier-Stokes equations
- Laminar and inviscid flows
- Vorticity and circulation
- Boundary layers



Credits: https://www.grc.nasa.gov/www/k-12/BGP/boundlay.html

Unit 4: Chaos and Turbulence in Fluids

- Onset of turbulence
- Energy cascade and Kolmogorov's theory
- Fractality in turbulence
- Chaos and mixing



Credits: CP1 student

Bibliography:

- Strogatz, S. H. (2018). Nonlinear dynamics and chaos
- Alligood, K. et al (1996). Chaos: An introduction to dynamical systems.
- Davidson, P. A. (2015). Turbulence: An introduction for scientists and engineers.
- Munson, B. R. et al. (2013). Fundamentals of fluid mechanics.

Description of the MSc course

Evaluation:

- **25%: Formative Evaluation** (Homework & Quizzes)
- **25%: Laboratory** (Software)
- **25%: Midterm Exam** (Paper & Presentation)
- **25%: Final Exam** (Paper & Presentation)

The passing grade for this MSc-level course is: **7.5 / 10.0.**

Please do your best in every assignment!

Class attendance:

- You are free to attend or not attend classes. I, however, suggest you should attend all classes.
- All classes will be recorded and posted on Moodle.

Useful repositories and extra bibliography:

If you have little experience with python and scientific programming, I suggest to look at my undergraduate courses:

- Computational Physics 1: https://github.com/wbandabarragan/computational-physics-1-arxiv
- Computational Physics 2: https://github.com/wbandabarragan/computational-physics-2-arxiv
- Python Programming And Numerical Methods: A Guide For Engineers And Scientists, 1st Edition, 2020 (https://pythonnumericalmethods.berkeley.edu/notebooks/Index.html).

Diagnostic Assessment 1

To begin the course, I would like to ask you a few questions.

Join at menti.com | use code 5656 2759

https://www.menti.com/al5o43vuo1me