UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Numerical Astrophysics

2627-1-F5803Q026

Aims

The objective of the course is to provide a foundational knowledge of the numerical methods and computational codes employed to solve differential equations typically encountered in astrophysical systems, with particular emphasis on relativistic dynamics around black holes.

At the end of the course, the student will have:

1. acquired knowledge (DdD1):

- of the principal numerical methods and open-source codes available in the field of astrophysics
- of the theory of post-Newtonian dynamics and geodesics in general relativity
- of selected aspects of processes happening around compact objects

2. developed the ability to apply the acquired knowledge to (DdD2):

- read and critically analyze scientific articles related to the topics addressed during the lectures
- proficiently use numerical methods for the integration of differential equations

3. developed critical thinking and independent judgement skills (DdD3):

- through the solution of problems related to specific physical systems
- by preparing technical reports and/or presentations on the activities carried out

4. developed communication skills (DdD4):

- through group work and discussions with other students enrolled in the course
- by presenting the work performed in English

5. developed autonomous learning skills (DdD5):

- through additional exercises designed to stimulate curiosity and deepen understanding of the subjects addressed
- by having acquired useful skills and methods to undertake a PhD program with in Physics or Astrophysics

Contents

Numerical methods for the solution of differential equations, Post-Newtonian dynamics, geodesic motion in general relativity, aspects of hydrodynamics and accretion.

Detailed program

Numerical methods for differential equations

1. Methods targeted to ordinary differential equations
2. Methods targeted to partial differential equations

Newtonian, Post-Newtonian and relativistic motion

1. Equations of Post-Newtonian dynamics
2. Geodesic motion in general relativity
3. Available codes for orbit integration

Aspects for hydrodynamics and accretion

1. Overview of hydro and accretion processes involving compact objects

Prerequisites

This course requires a basic knowledge of special and general relativity. The latter can be obtained by following the Relativistic Astrophysics or General Relativity courses. For the practical lectures, programming skills are necessary given the numerical oriented approach of the course. Python programming language will be the baseline language employed.

Teaching form

All lessons are held in person:

1. 13 lessons of 2 hours each in frontal-teaching delivery mode,
2. 14 practice sessions of 2 hours each in interactive mode.

During the lessons the theoretical bases will be exposed and the most recent theoretical and experimental results will be discussed. The lessons will take place partly on the blackboard and partly through the use of slides. Slides will be uploaded before the lectures on the course e-learning site. During the practice sessions the students will learn (under the guidance of the teacher) how to write numerical codes for the solution of differential equations and how to use publicly-available codes. The use of a laptop is required for the practice sessions. All lectures and practice sessions are held in English.

Textbook and teaching resource

Main textbooks:

1. "Gravity: Newtonian, Post-Newtonian, Relativistic", by E. Poisson, C. Will
2. "A First Course in General Relativity" (2nd edition), by B. Schutz
3. "A Relativist's Toolkit: The Mathematics of Black-Hole Mechanics", by E. Poisson
4. "A First Course in the Numerical Analysis of Differential Equations", by A. Iserles
5. "Introduction to Numerical Methods in Differential Equations", by M. H. Holmes

Other useful textbooks:

1. "Black Holes, White Dwarfs and Neutron Stars", by S. L. Shapiro and S. A. Teukolsky
2. "Numerical methods for conservation laws", by Randall J. LeVeque
3. "Numerical Recipes: the art of scientific computing" (3rd edition), by W. H. Press, S. A. Teukolsky, W. T. Vetterling, B. P. Flannery
4. "Numerical Methods in Engineering with Python 3", by Kiusalaas

Semester

I year, second semester

Assessment method

The final oral exam consists of a discussion on arguments encountered during the course. Specifically, it will be structured in two parts.

Part I: Students are expected to focus on a problem of their choice (a list of possible suggestions will be available at the end of the course) and elaborate a strategy to tackle it numerically. This part must be completed in advance with respect to the exam date. The day of the exam, the discussion will start with a presentation of the chosen work and must contain:

- an overview of the physical problem;
- an explanation of the strategy and numerical approach followed;
- a description of the obtained results alongside their physical interpretation.

The presentation can be performed using slides or jupyter notebooks.

Part II: The exam will continue discussing a random topic covered during lectures.

Books and notes cannot be used during the oral exam.

Office hours

by appointment, on line or in person.

Sustainable Development Goals

QUALITY EDUCATION | INDUSTRY, INNOVATION AND INFRASTRUCTURE