UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Course guide
230862 - CAS - Computational Astrophysics

Last modified: 02/06/2022

Unit in charge: Barcelona School of Telecommunications Engineering
Teaching unit: 748 - FIS - Department of Physics.

Degree: MASTER'S DEGREE IN ENGINEERING PHYSICS (Syllabus 2018). (Optional subject).

Academic year: 2022 **ECTS Credits:** 4.0 **Languages:** English

LECTURER

Coordinating lecturer: Consultar aquí / See here: https://telecos.upc.edu/ca/estudis/curs-actual/professorat-responsables-coordinadors/responsables-assignatura.

Others: Consultar aquí / See here: https://telecos.upc.edu/ca/estudis/curs-actual/professorat-responsables-coordinadors/professorat-assignat-idioma

PRIOR SKILLS

Even though the course is self-contained a previous knowledge of basic concepts of Astrophysics, Fluid mechanics and Statistics is appreciated.

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Basic:
CB6. (ENG) Poseer y comprender conocimientos que aporten una base u oportunidad de ser originales en el desarrollo y/o aplicación de ideas, a menudo en un contexto de investigación
CB7. (ENG) Que los estudiantes sepan aplicar los conocimientos adquiridos y su capacidad de resolución de problemas en entornos nuevos o poco conocidos dentro de contextos más amplios (o multidisciplinares) relacionados con su área de estudio.
CB8. (ENG) Que los estudiantes sean capaces de integrar conocimientos y enfrentarse a la complejidad de formular juicios a partir de una información que, siendo incompleta o limitada, incluya reflexiones sobre las responsabilidades sociales y éticas vinculadas a la aplicación de sus conocimientos y juicio.
CB9. (ENG) Que los estudiantes sepan comunicar sus conclusiones ¿y los conocimientos y razones últimas que las sustentan a públicos especializados y no especializados de un modo claro y sin ambigüedades
CB10. (ENG) Que los estudiantes posean las habilidades de aprendizaje que les permitan continuar estudiando de un modo que habrá de ser en gran medida autodirigido o autónomo.

TEACHING METHODOLOGY

The subject will combine traditional blackboard teaching and audiovisual media with learning based in computer numerical techniques. Once the theoretical foundations have been introduced, the student will we asked to solve numerical exercises and build/run numerical simulations. Such numerical work will be done either by using existing software or building small programs. Eventually, some (a few) of the sessions may be imparted 'on-line'. Additionally, the scientific contents of the course may be re-inforced with specialized seminars on different topics connected to the Computational Astrophysics.

LEARNING OBJECTIVES OF THE SUBJECT

The main aim of the course is to facilitate the learnig of a number of numerical techniques which often appear in many topics in Astrophysics and Cosmology. Several basic techniques of broad usefulness will be explained. These techniques are important to both: students with a particular interest in observational techniques (massive astronomical data-bases, automatic reduction of observational data, reduction and calibration of stellar spectra) as well as to students interested in theoretical astrophysics (Three-dimensional hydrodynamics and magneto-hydrodynamics or chemical evolution models and stellar population dynamics using Monte Carlo techniques).

After finishing this course the student will be in command of advanced numerical techniques, as for example multidimensional Lagrangian hydrodynamics, nuclear reaction networks, spectral analysis or efficient algorithms to handle with large data-bases of astronomical data. Summarizing, the ultimate goal is that the student is able to cope with several general and important problems n modern Astrophysics using/understanding the adequate numerical tools and techniques.

STUDY LOAD

Type	Hours	Percentage
Hours large group	36,0	36.00
Self study	64,0	64.00

Total learning time: 100 h

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CONTENTS

Computational Astrophysics

Description:
PROGRAM

1. Multidimensional Hydrodynamics
1.1 The Lagrangian and Eulerian formalisms in CFD
1.2 The hydrodynamic Euler equations
1.3 Hydrodynamic codes addressed to Astrophysical simulations
1.3.1 Eulerian versus Lagrangian methods and codes
I 1.3.2 Explicit versus Implicit methods
1.4 The Smoothed Particle Hydrodynamics method
1.4.1 Interpolation
1.4.2 Variable resolution in space and time
1.4.3 Lagrangian SPH equations
1.4.5 Applications of the Eulerian equations
1.4.6 Heat conduction and mass diffusion
1.4.7 Viscosity
1.4.8 Application to shocks and rarefaction problems
1.4.9 Astrophysical applications
1.4.10 Other applications
1.5 Introduction to the multidimensional Magnetohydrodynamics with SPH
1.6 Future developments

2. Astrophysical applications of Monte Carlo methods
2.1 Overview of basic concepts
2.1.1 Random numbers vs. pseudo-random numbers
2.2 Random number generators
2.2.1 Desirable statistical properties
2.2.2 Types of generators: a) linear congruential generator; b) multiplicative congruential generator; c) Tausworth generator
2.2.3 Good and bad generators. Improvement techniques
2.3 Transformation methods
2.3.1 Uniform distribution and linear transformation.
2.3.2 Inversion technique
2.3.3 Box-Muller method.
2.3.4 Accepting-rejecting method.
2.4 Some applications of Monte Carlo methods in Astrophysics
2.4.1 Globular clusters
2.4.2 The Galaxy

3. Spectroscopic data analysis techniques.
3.1 Introduction to observational astronomy
3.1.1 Telescopes.
3.1.2 CCD cameras.
3.1.3 The electromagnetic spectrum.
3.1.4 Introduction to spectroscopy.
3.2 Data reduction
3.2.1 Bias images and debiassing.
3.2.2 Flat-field spectra and flat-field correction.
3.3.3 Extraction of one-dimension spectra.
3.3 Calibration
3.3.1 Arc-lamp spectra and wavelength calibration.
3.3.2 Flux standard spectra and flux calibration.
3.4 Data analysis
3.4.1 Reduction and calibration of real spectra

Specific objectives:
To know the scientific foundations of a subset of numerical methods widely used in computational astrophysics. To work with

practical examples of algorithms related to these methods and build practical calculation/simulation programs associated with these methods. An example would be the elaboration of a basic three-dimensional hydrodynamic simulation code adapted to the simulation of an explosion or to the collapse of a self-gravitating gas cloud.

Related activities:
The course is complemented by at least one 1.30-2 hour Seminar given by an external expert researcher in any of the techniques explained in the course.

Full-or-part-time: 135h
Theory classes: 40h
Practical classes: 10h
Guided activities: 40h
Self study : 45h

GRADING SYSTEM

Final grades will take into account the following items:
1) Regular attendance to the theoretical expositions
2) Satisfactory execution of practical exercises
3) Project based learning (PBL)
4) Public lecture of the PBL results

EXAMINATION RULES.

Because the number of students is not high, these will be decided throughout the course. There is not any re-evaluation test in Computational Astrophysics.

BIBLIOGRAPHY

Basic:
- Monaghan , J.J. "Smoothed Particle Hydrodynamics". Monaghan J.J. Annual Review of Astronomy and Astrophysics, Vol 30, 1992 [on line]. [Consultation: 02/06/2022]. Available on: https://ui.adsabs.harvard.edu/link_gateway/1992ARA%26A..30..543M/ADS_PDF.
- Kroese, D.P., Taimre, Z., Botev, Z.I.. Handbook of Monte Carlo methods. first. Hoboken, NJ: John Wiley & Sons, Inc, 2011. ISBN 9780470177938.
- Teukolsky, W.H, Vetterling, S.A, Flannery, B. Numerical Recipes: the art of scientific computing. 3rd ed. New York: Cambridge University Press, 2007. ISBN 9780521880688.

RESOURCES

Other resources:
The course relies on simple resources, such as audiovisual material and computing algorithms provided by the teachers of the subject.