

# SACHA CARDONNA

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## Current position

### Ph.D. candidate in Mathematics.

10/2023 - Present

*Institut Montpellierain Alexander Grothendieck – Montpellier, France.*

*Title.* Modeling and numerical study of free-border problem and wave-structure interaction.

*Advisors.* François Vilar & Fabien Marche.

*Funding.* French ministry fellowship, ranked 1<sup>st</sup> at I2S Doctoral School admission exam.

△ Research interests	1
△ Education	1
△ Work experiences	1
△ Teaching activities	2
△ Software development	2
△ Grants	3
△ Communications	3
△ Responsibilities	3
△ Scientific diffusion	3
△ Internships	4
△ Complementary training	4
△ Computer skills	5
△ Academic projects	5
△ Courses taken	5
△ Languages	6

## Research interests

### *Models.*

Conservation laws,  
Hyperbolic systems,  
Models coupling.

### *Numerics.*

DG & FV methods,  
Well-balanced schemes,  
ALE approaches.

### *Applications.*

Fluid mechanics,  
Nonlinear Shallow-Water,  
Dispersive PDEs.

### *Scientific computing.*

O.-O. programming,  
Generical programming,  
Parallel computing.

## Education

### Graduate studies in Mathematics.

09/2020 - 06/2023

*Faculty of Sciences – Montpellier, France.*

Master's Degree in Theoretical and Numerical Analysis of PDEs (*highest honours*).

Master's Degree in Fundamental Mathematics.

*Highlights.* 1<sup>st</sup> in Theoretical Analysis, Numerical Analysis, Research Traineeship, a Posteriori Estimates courses.

*Rank.* Valedictorian (GPA: 4.0).

### Undergraduate studies in Mathematics & Physics.

09/2017 - 05/2020

*Faculty of Sciences – Montpellier, France.*

Bachelor's Degree in Pure and Applied Mathematics (*first-class honours*).

Associate's Degree in Mathematics & Physics (*first-class honours*).

*Highlights.* 1<sup>st</sup> in Numerical Analysis of ODEs, Convex Optimization & Classical Mechanics courses.

*Rank.* Consistently ranked in the top 10% best students (GPA: 3.7).

## Work experiences

### Ph.D. candidate in Mathematics.

10/2023 - Present

*Institut Montpellierain Alexander Grothendieck – Montpellier, France.*

### Teaching assistant at Department of Mathematics.

10/2023 - Present

*Faculty of Sciences & Engineering School Polytech – Montpellier, France.*

### Research intern.

03 - 07/2023

*Institut Montpellierain Alexander Grothendieck – Montpellier, France.*

## Teaching activities

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**Numerical analysis of differential equations** (3<sup>rd</sup> year B.Sc.) 2024 - 2025

*Faculty of Sciences – Montpellier, France.*

*Role.* Tutorial classes, coding, exam marking.

*Topics.* Numerical schemes (Euler, Runge-Kutta, Finite Difference, ...), ordinary and partial differential equations.

**Convex optimization** (2<sup>nd</sup> year B.Sc.) 2024 - 2025

*Faculty of Sciences – Montpellier, France.*

*Role.* Tutorial classes, coding, exam marking.

*Topics.* Unconstrained and constrained extremas, applied mathematics, mathematical learning.

**Mathematical tools for sciences and engineering** (1<sup>st</sup> year B.Sc.) 2024 - 2025

*Faculty of Sciences – Montpellier, France.*

*Role.* Tutorial classes, exam writing and marking.

*Topics.* Logical reasoning, set theory, real variable functions, integral calculus, 1<sup>st</sup>-order differential equations.

**Differential calculus & multivariable integration** (2<sup>nd</sup> year B.Sc.) 2023 - 2024

*Engineering School Polytech – Montpellier, France.*

*Role.* Tutorial classes, exam writing and marking.

*Topics.* Differential calculus, multivariable integration, topology, bilinear algebra.

**Supervised mathematical assignments** (2<sup>nd</sup> year B.Sc.) 2023 - 2024

*Engineering School Polytech – Montpellier, France.*

*Role.* Supervising various groups of students to prepare midterms and exams.

*Topics.* Differential calculus, multivariable integration, topology, bilinear algebra.

## Software development

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**WaveBox 2024 – Multi-models C++ numerical platform for water-waves equations.**

WaveBox is a multi-model numerical platform created by Fabien Marche, dedicated to approximating solutions of various shallow water asymptotics in two-dimensional domains ( $d = 2$ ). It contains Hybridized Discontinuous Galerkin (HDG) and DG methods on general unstructured meshes (Saint-Venant, Boussinesq, and Green-Naghdi equations). Main features include:

- Sub-models CPU-GPU co-processing;
- Arbitrary order of accuracy ( $h$ - and  $p$ -adaptivity);
- Robust treatment of run-up and flooding processes (strict maximum-principle enforcement);
- Well-balancing for motionless steady states;
- Unstructured meshes & mesh subdivision;
- Wave breaking treatment with a dynamic switching strategy.

*Contributions.* Development of a new section dedicated to high-order monolithic DG-FV schemes, with grid subdivisions and a priori stabilization methods, in 1D & 2D. Development of several visualization tools on Python. Git integration and maintenance with Fabien Marche.

**DG4SCL – Compact and student friendly DG code for 1D SCL.**

Development of a compact C++ code to address Discontinuous Galerkin (DG) schemes for 1D conservation laws. The project was designed with an emphasis on simplicity and clarity, ensuring that its structure and implementation are accessible and easy to understand, especially for students discovering DG methods.

*Contributions.* Full development "from scratch", with the help of Ali Haidar and François Vilar.

## Grants

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**Competition of *Informations, Structures, Systèmes* (I2S) Doctoral School.** 2023

Highly selective admission exam to get Ph.D. scholarship from French Ministry of Research. Ranked 1<sup>st</sup> among all candidates in mathematics.

*Funding.* 125,500€ over 3 years.

## Communications

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### Poster at Ph.D. Day.

03/2024

*Institut Montpellierain Alexander Grothendieck – Montpellier, France.*

**Title.** Monolithic DG-FV subcell convex property preserving scheme for Shallow Water.

### Talk at Séminaire des Doctorants.

10/2023

*Institut Montpellierain Alexander Grothendieck – Montpellier, France.*

**Title.** Modeling, solving & implementing PDEs from waves-structure interactions.

## Responsibilities

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### Member of the Sustainable Development Committee at the IMAG laboratory.

2024 - Present

Representing Ph.D. students in meetings and decision-making processes, contributing to the annual GHG (greenhouse gas) inventory and proposing strategies to improve the lab's environmental impact.

### Student Representative of Master's Degree in Applied Mathematics.

2023 - 2024

Representing graduate students in various reunions of development council, in order to convey student comments and improve the formation.

## Scientific diffusion

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### Mastering games with Mathematics – MathC2+ program.

06/2024

*Collaboration with IRES & LabEx NUMEV – Montpellier, France.*

Introducing mathematics from different games and algorithms to win easily.

- Tic-Tac-Toe to introduce game theory and combinatorics, helping students anticipate moves and understand optimal play through the work of Newell et al.;
- Mastermind, focusing on logic and deduction, such as using Knuth's algorithm to break the code;
- Spot It! (Dobble) to demonstrate how abstract concepts like combinatorial designs and projective geometry can be used not only for research purposes but also in designing board games.

The culmination of this internship is the development of a code to create a homemade Spot It game cards with their favorite pictures or logos.

### MATH.en.JEANS congress – Promoting mathematical research to high-schoolers.

05/2024

*Supervised by Louise Nyssen (IMAG & IRES) – Montpellier, France.*

MATH.en.JEANS congress aims to introduce mathematics research to young students, under the leadership of a researcher and their teacher.

- Chain is based on volunteers (students, teachers, researchers), and is not graded. The twinning system allows students to explain and compare their ideas with those of a group of students who have worked on the same subject, in another establishment in the same city;
- Throughout France, more than 200 establishments host a MATH.en.JEANS workshop each year, the culmination being the presentation by students of the results of their work at a national conference.

### Mathematics & Modeling – MathC2+ program.

04/2024

*Collaboration with IRES & LabEx NUMEV – Montpellier, France.*

Introducing applied mathematics, modeling and scientific computing to high-schoolers.

- Introducing some essential mathematics notions, followed by a hands-on activity measuring the free fall times of different objects, obtaining the motion equation as a second-degree polynomial;
- Discovering numerical root finding methods, highlighting their significance in physics and engineering, complemented by constructing mini catapults in order to explore physical principles for optimization, linking these to motion equations;
- Practicing Python programming, developing an analytical and numerical solver for the quadratic equation  $ax^2 + bx + c = 0$ , serving as the capstone project.

### Introduction to Applied Mathematics – Supervision of 9th grade trainees.

12/2023

*Collaboration with IRES & IMAG – Montpellier, France.*

Exploring the application of mathematics to real-world scenarios by examining two trains on a collision course, focusing on calculating their meeting point. This involves theoretical calculations of motion and numerical solutions via the bisection method, highlighting the intersection of mathematics, problem-solving, and programming.

Visiting Peytavin & Saint-Pierre-Saint-Paul schools in order to promote mathematics professions, talk about our thesis subject and our student path with high schoolers.

## Internships

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**Finite-Volume Subcells correction on discontinuous Galerkin schemes.**

03 - 07/2023

Building and implementing a new strategy for stabilizing discontinuous Galerkin numerical methods using a Finite-Volume subcells type approach for the Nonlinear Shallow-Water equations. We consider here an a priori approach, more precisely a monolithic subcell dG/FV convex property preserving scheme.

*Advisors.* François Vilar & Fabien Marche.

**Asymptotic analysis of PDEs sequences and homogenization theory.**

02 - 05/2022

We consider two problems, including a Dirichlet problem on a variable open set. Ice fog forms when water vapour, mainly resulting from human activities, enters the atmosphere. This vapor condenses into droplets which quickly freeze, giving rise to particles of ice without a well-defined crystalline form. The objective is to model it as a homogenization problem.

*Advisor.* Michel Bellieud.

**From differential geometry to mathematical billiards.**

03 - 05/2021

Studying one of the simplest dynamical system, the mathematical billiard where we characterize the periodic trajectories by their initial angle of shot.

*Advisor.* Daniel Massart.

**Proof of Dirichlet Prime Number theorem.**

01 - 04/2020

Demonstrating that, for  $a, b \in \mathbb{N}^*$ , such that  $\gcd(a, b) = 1$ , the arithmetic progression  $\{an + b\}_{n \in \mathbb{N}}$  contains an infinity of prime numbers. Such a proof needs various theories, like complex analysis or group theory.

*Advisor.* Sylvain Brochard.

## Complementary training

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**Creative Pedagogy (Level 1&2).**

01 - 03/2024

The program enhances teaching by diversifying pedagogical approaches, promoting collaborative and engaging learning experiences, and incorporating creative and risk-taking methods.

- Focus on adapting teaching styles to various contexts, fostering interactivity, and developing collaborative projects;
- Aims to innovate the learning model to align with 21st-century challenges, strengthening academic and socio-economic ties.

*Advisor.* Céline Avenel & Alexander Arenas-Canon.

**Advanced Programming for Scientific Computing.**

10 - 12/2024

High-level course based on C++ programming for scientific computing.

- Memory management, object-oriented programming concepts, and advanced data processing techniques for scientific research;
- Use of essential pre/post-processing tools in the context of complex scientific simulations;
- Emphasizes the importance of modern collaborative work tools, such as version control systems.

*Advisor.* Fabien Marche.

**Management & Leadership.**

01/2024

The training aims at understanding the challenges of the managing function, having authority in our function and the adequate postures, as a manager, with different interlocutors.

*Advisor.* Audrey Agbodjogbe-Richard.

**Research Ethics.**

01 - 03/2023

This MOOC training equips participants with a deep understanding of ethical principles in scientific research, emphasizing the significance of integrity, the impact of technological advancements, and the responsibilities of researchers and institutions. It delves into navigating conflicts of interest and values, preparing doctoral students, researchers, and citizens to address contemporary ethical challenges in science.

*Reference establishment.* Lyon's University.

## Artificial Intelligence and Ethics.

12/2023

This seminar explores the intersection of artificial intelligence technology and ethical considerations, examining the implications of AI on privacy, bias, and decision-making in society. It aims to equip participants with the knowledge to navigate the moral dilemmas posed by AI advancements, fostering responsible development and use of AI technologies.

*Advisor.* Laurent Fauré.

## Scientific Writing & Publishing.

12/2023

This MOOC training aims at being proficient in reading and analyzing scientific articles, understanding their structure, mastering the writing rules for each section, comprehending the peer-review process, and applying ethical guidelines in scientific writing.

*Reference establishment.* Institut de Recherche pour le Développement.

## Computer skills

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<b>Programming</b>	C/C++, Python, notions of Fortran.
<b>Mathematics softwares</b>	FreeFEM++, Matlab, Scilab, gnuplot, Maple, Mathematica.
<b>Markup languages</b>	HTML, CSS, PHP.
<b>Typesetting systems</b>	L <sup>A</sup> T <sub>E</sub> X, Beamer, Microsoft Office ( <i>Word &amp; PowerPoint</i> ).
<b>Operating systems</b>	Linux ( <i>Kali &amp; Debian</i> ), Windows, macOS.
<b>Creation softwares</b>	Adobe Creative Cloud, Audacity, Final Cut Pro X.

## Academic projects

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### Hybrid High-Order method on Leray-Lions operators.

12/2022

*Advanced Numerical Analysis, introduction to Hybrid High-Order method course.*

Studying a new non-conform finite-element method called Hybrid High-Order and its main discrete functional analysis results on Leray-Lions operators.

*Advisor.* Daniele Di Pietro.

### Müller's SPH C++ implementation for fluid dynamics.

11/2022

*A Posteriori Estimates & Mesh Adaption course.*

Building and implementing Smooth Particle Hydrodynamics method for a C++ simulation.

*Advisor.* Bijan Mohammadi.

### Some results about measure theory.

05 - 09/2022

*Personal project lead during summer break.*

Proving measure theory results, including differentiation of Radon measures, Besicovitch & Vitali covering theorems, Tietze & Lusin's theorems.

*Advisor.* Michel Bellieud.

### Finite-element resolution and FreeFEM++ simulation.

05 - 04/2022

*Finite-Element method course.*

Studying and implementing a Dirichlet problem with mixed boundary conditions on FreeFEM++.

*Advisor.* Vanessa Lleras.

### Machine Learning code for database analysis.

10/2021

*Machine Learning & Convex Optimization course.*

Database analysis and programming regression methods for machine learning on Python.

*Advisor.* Bijan Mohammadi.

### Numerical interpolation and its limits.

2018

*Personal project lead during associate's degree.*

Studying polynomial interpolation and Runge's phenomenon.

*Advisor.* Sylvain Brochard.

## Courses taken

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**Fundamental courses.** Theoretical Analysis of PDEs – Functional Analysis & Distribution Theory – Differential Geometry – Measure and Integration Theory – Complex Analysis – Topology of Metric Spaces – Galois Theory – Category Theory – Ring & Group Theory – Differential Equations & Calculus – Probability Theory – Euclidian Geometry – Linear & Bilinear Algebra – Real Analysis – Calculus.

**Applied and specialized courses.** Numerical Analysis of PDEs – Numerical Modeling – Homogenization for Navier-Stokes – Scientific Computing – Machine Learning & Convex Optimization – *A Posteriori* Estimates & Mesh Adaption – Fourier Transform & Convolution for Inverse Problems – Deterministic & Stochastic Modeling.

**Physics courses.** Solid & Fluid Mechanics – Electromagnetism – Electrostatics & Magnetostatics – Thermodynamics – Wave & Geometrical Optics – Electrohydrodynamics – Experimental Physics.

## Languages

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**French:** native (TEF score: C2)    **English:** fluent (IELTS 7.5)    **Spanish:** intermediate.

*Last update.* Friday 29<sup>th</sup> November, 2024.