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**Université Nice - Sophia
Antipolis**

Activity Report 2019

Project-Team CASTOR

Control, Analysis and Simulations for
TOKamak Research

IN COLLABORATION WITH: Laboratoire Jean-Alexandre Dieudonné (JAD)

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
**Earth, Environmental and Energy
Sciences**

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Project-Team CASTOR

Creation of the Team: 2012 July 01, updated into Project-Team: 2014 July 01

Keywords:

Computer Science and Digital Science:

- A6. - Modeling, simulation and control
- A6.1. - Methods in mathematical modeling
 - A6.1.1. - Continuous Modeling (PDE, ODE)
 - A6.1.4. - Multiscale modeling
 - A6.1.5. - Multiphysics modeling
- A6.2. - Scientific computing, Numerical Analysis & Optimization
 - A6.2.1. - Numerical analysis of PDE and ODE
 - A6.2.6. - Optimization
 - A6.2.7. - High performance computing
 - A6.2.8. - Computational geometry and meshes
- A6.3. - Computation-data interaction
 - A6.3.1. - Inverse problems
 - A6.3.2. - Data assimilation
 - A6.3.4. - Model reduction
- A6.4. - Automatic control
 - A6.4.1. - Deterministic control
 - A6.4.4. - Stability and Stabilization

Other Research Topics and Application Domains:

- B4. - Energy
 - B4.2.2. - Fusion

1. Team, Visitors, External Collaborators

Research Scientists

- Hervé Guillard [Team leader since July 2019, Inria, Senior Researcher, HDR]
- Florence Marcotte [Inria, Researcher, from Nov 2019]
- Sebastian Minjeaud [CNRS, Researcher]
- Richard Pasquetti [CNRS, Emeritus Researcher, HDR]

Faculty Members

- Jacques Blum [Team leader until Jun 2019, Univ de Nice - Sophia Antipolis, Professor, HDR]
- Cédric Boulbe [Univ Côte d'Azur, Associate Professor]
- Boniface Nkonga [Univ Côte d'Azur, Professor]
- Francesca Rapetti [Univ de Nice - Sophia Antipolis, Associate Professor]
- Afeintou Sangam [Univ Côte d'Azur, Associate Professor]

PhD Students

- Ashish Bhole [Univ Côte d'Azur, PhD Student]
- Ali Aboudou Elarif [Inria, PhD Student]
- Xiao Song [CEA, PhD Student, until Nov 2019]

Technical staff

Blaise Faugeras [CNRS, Engineer]

Administrative Assistant

Montserrat Argente [Inria, Administrative Assistant]

Visiting Scientists

Praveen Chandrashekarappa [Tata Institute of Fundamental Research, from Mar 2019 until May 2019]

Guillaume Leroy [Univ de Nice - Sophia Antipolis, until Feb 2019]

External Collaborator

Didier Auroux [Univ Côte d'Azur]

2. Overall Objectives

2.1. Presentation

In order to fulfill the increasing demand, alternative energy sources have to be developed. Indeed, the current rate of fossil fuel usage and its serious adverse environmental impacts (pollution, greenhouse gas emissions, ...) lead to an energy crisis accompanied by potentially disastrous global climate changes.

Controlled fusion power is one of the most promising alternatives to the use of fossil resources, potentially with a unlimited source of fuel. France with the ITER (<http://www.iter.org/default.aspx>) and Laser Megajoule (<http://www-lmj.cea.fr/>) facilities is strongly involved in the development of these two parallel approaches to master fusion that are magnetic and inertial confinement. Although the principles of fusion reaction are well understood from nearly sixty years, (the design of tokamak dates back from studies done in the '50 by Igor Tamm and Andreï Sakharov in the former Soviet Union), the route to an industrial reactor is still long and the application of controlled fusion for energy production is beyond our present knowledge of related physical processes. In magnetic confinement, beside technological constraints involving for instance the design of plasma-facing component, one of the main difficulties in the building of a controlled fusion reactor is the poor confinement time reached so far. This confinement time is actually governed by turbulent transport that therefore determines the performance of fusion plasmas. The prediction of the level of turbulent transport in large machines such as ITER is therefore of paramount importance for the success of the researches on controlled magnetic fusion.

The other route for fusion plasma is inertial confinement. In this latter case, large scale hydrodynamical instabilities prevent a sufficiently large energy deposit and lower the return of the target. Therefore, for both magnetic and inertial confinement technologies, the success of the projects is deeply linked to the theoretical understanding of plasma turbulence and flow instabilities as well as to mathematical and numerical improvements enabling the development of predictive simulation tools.

CASTOR gathers the activities in numerical simulation of fusion plasmas with the activities in control and optimisation done in the laboratory Jean-Alexandre Dieudonné of the University of Nice. The main objective of the CASTOR team is to contribute to the development of innovative numerical tools to improve the computer simulations of complex turbulent or unstable flows in plasma physics and to develop methods allowing the real-time control of these flows or the optimisation of scenarios of plasma discharges in tokamaks. CASTOR is a common project between Inria (<http://www.inria.fr/centre/sophia>) and the University of Nice Sophia-Antipolis and CNRS through the laboratory Jean-Alexandre Dieudonné, UMR UNS-CNRS 7351, (<http://math.unice.fr>).

3. Research Program

3.1. Plasma Physics

Participants: Jacques Blum, Cédric Boulbe, Blaise Faugeras, Hervé Guillard, Holger Heumann, Sebastian Minjeaud, Boniface Nkonga, Richard Pasquetti, Afeintou Sangam.

The main research topics are:

1. Modelling and analysis
 - Fluid closure in plasma
 - Turbulence
 - Plasma anisotropy type instabilities
 - Free boundary equilibrium (FBE)
 - Coupling FBE – Transport
2. Numerical methods and simulations
 - High order methods
 - Curvilinear coordinate systems
 - Equilibrium simulation
 - Pressure correction scheme
 - Anisotropy
 - Solving methods and parallelism
3. Identification and control
 - Inverse problem: Equilibrium reconstruction
 - Open loop control
4. Applications
 - MHD instabilities : Edge-Localized Modes (ELMs)
 - Edge plasma turbulence
 - Optimization of scenarii

4. New Results

4.1. On the identification of the electron temperature profile from polarimetry Stokes vector measurements in Tokamak free-boundary equilibrium reconstruction

Participants: Blaise Faugeras, Francesco Orsitto.

This paper reports numerical investigations on the identification of the electron temperature profile T_e from interferometry and polarimetry Stokes vector measurements with the equilibrium code NICE (Newton direct and Inverse Computation for Equilibrium). This latter enables the consistent resolution of the inverse equilibrium reconstruction problem in the framework of nonlinear free-boundary equilibrium coupled to the Stokes model equation for polarimetry. We find that for ITER plasma with high I_p , N_e and T_e the identification from noisy measurements is possible (Project EUROfusion / WP01Jet Campaigns (WPJET1) .

4.2. Equilibrium reconstruction for the JT-60SA tokamak

Participant: Blaise Faugeras.

Twin experiments were performed with this tokamak geometry in the framework of the EUROfusion / WP10 JT-60SA (WPSA) project.

4.3. Plasma boundary reconstruction for the ISTTOK tokamak

Participants: Blaise Faugeras, Rui Coelho, R. Santos.

Plasma boundary reconstruction is one of the main tools to provide a reliable control and tokamak performance. We explore the feasibility for the ISTTOK tokamak (Portugal) of a reconstruction method based on calculated vacuum magnetic flux map and plasma intersection with the wall. We show that via square wave input response curves and pre-processing of the poloidal field coil currents, it is possible to build for ISTTOK a simple scaling model for the effective equilibrium magnetic fields, and perform plasma boundary reconstruction using the algorithm VacTH. This algorithm, included in the NICE numerical code suite, relies on the decomposition of the poloidal flux in toroidal harmonics. The reconstructed plasma boundary is shown for a given discharge and its shape and position are shown to evolve consistently with the typical timescale evolution of ISTTOK discharges. This provides an opportunity of using this plasma boundary reconstruction method as a diagnostic tool for ISTTOK.

4.4. Implementation of a method enabling error bar computations for all reconstructed equilibrium quantities

Participant: Blaise Faugeras.

Error bars on control variables are directly given by the inverse of the Hessian of the minimized cost function. This is not the case for other quantities such as the safety factor profile for example, and the computation of error bars for these important output quantities necessitate the non-trivial computation of their (discrete) derivatives with respect to the control variables as well as the state variables.

4.5. New developments on the code NICE

Participant: Blaise Faugeras.

Developments have been done on the code NICE:

- Implementation of a mode 'without plasma' for magnetostatic computations.
- Implementation of pressure constraints in NICE for IMAS tested on JET data.
- Regular updates of the relaxed NICE actor in IMAS (EUROfusion / WP13 Code Development for Integrated Modeling)
- A Matlab interface has been developed to run the free boundary direct, evolutive, and inverse static modes of NICE.

4.6. Automatic identification of the plasma equilibrium operating space in tokamaks

Participants: Blaise Faugeras, Xia Song, Eric Nardon, Holger Heumann.

In order to identify the plasma equilibrium operating space for future tokamaks, a new objective function is introduced in the inverse static free-boundary equilibrium code FEEQS.M. This function comprises terms which penalize the violation of the central solenoid and poloidal field coils limitations (currents and forces). The penalization terms do not require any weight tuning. Hence, this new approach automates to a large extent the identification of the operating space. As an illustration, the new method is applied on the ITER 15 and 17MA inductive scenarios, and similar operating spaces compared to previous works are found. These operating spaces are obtained within a few (~ 3) hours of computing time on a single standard CPU.

4.7. Automating the design of Tokamak experiment scenarios

Participants: Jacques Blum, Holger Heumann.

The real-time control of plasma position, shape and current in a tokamak has to be ensured by a number of electrical circuits consisting of voltage suppliers and axisymmetric coils. Finding good target voltages/currents for the control systems is a very laborious, non-trivial task due to non-linear effects of plasma evolution. We introduce here an optimal control formulation to tackle this task and present in detail the main ingredients for finding numerical solutions: the finite element discretization, accurate linearizations and Sequential Quadratic Programming. Case studies for the tokamaks WEST and HL-2M highlight the flexibility and broad scope of the proposed optimal control formulation.

4.8. Coupling NICE-METIS

Participants: Jean François Artaud, Jacques Blum, Cédric Boulbe, Blaise Faugeras.

The free boundary equilibrium code NICE has been coupled to the fast transport solver METIS in a Matlab workflow. A first test case has been proposed on ITER. This work has been done for the project Eurofusion WPCD.

4.9. Advances in high order mixed finite elements for Maxwell's equations

Participant: Francesca Rapetti.

The implementation of high order curl- or div-conforming finite element spaces is quite delicate, especially in the three-dimensional case. I have worked on an implementation strategy, which has been applied in the open source finite element software FreeFem++. In particular, I have used the inverse of a generalized Vandermonde matrix to build a basis of generators in duality with the degrees of freedom, which then provides in FreeFem++ an easy-to-use but powerful interpolation operator. With Marcella Bonazzoli, now at the Inria Team DEFI in Saclay, I have carefully addressed the problem of applying the same Vandermonde matrix to possibly differently oriented tetrahedra of the mesh over the computational domain. [17]

High order mixed finite element spaces generally lack natural choices of bases but they do have spanning families. I have worked on these FEs for simplicial meshes and proven theoretically their effectiveness. I have also commented on some aspects of a new set of degrees of freedom, the so-called weights on the small simplices, to represent discrete functions in these spaces [11].

4.10. Construction of divergence-free bases

Participants: Francesca Rapetti, Ana Alonso Rodriguez.

I have worked to propose and analyze an efficient algorithm for the computation of a basis of the space of divergence-free Raviart-Thomas finite elements. The algorithm is based on graph techniques. The key point is to realize that, with very natural degrees of freedom for fields in the space of Raviart-Thomas finite elements of degree $r + 1$ and for elements of the space of discontinuous piecewise polynomial functions of degree $r \geq 0$, the matrix associated with the divergence operator is the incidence matrix of a particular graph. By choosing a spanning tree of this graph, it is possible to identify an invertible square submatrix of the divergence matrix and to compute easily the moments of a field in the space of Raviart-Thomas finite elements with assigned divergence. The analyzed approach is then used to construct a basis of the space of divergence-free Raviart-Thomas finite elements. The numerical tests show that the performance of the algorithm depends neither on the topology of the domain nor on the polynomial degree r [16].

4.11. First steps to polytopal/polyhedral meshes

Participant: Francesca Rapetti.

Merging ideas from compatible discretisations and polyhedral methods, I have worked with D. Di Pietro and J. Droniou to construct novel fully discrete polynomial de Rham sequences of arbitrary degree on polygons and polyhedra. The spaces and operators that appear in these sequences are directly amenable to computer implementation. Besides proving exactness, we have shown that the usual sequence of Finite Element spaces forms, through appropriate interpolation operators, a commutative diagram with other proposed sequence, which ensures suitable approximation properties. A discussion on reconstructions of potentials and discrete L^2 -products completes the work [14].

4.12. C^1 finite elements on triangular meshes

Participants: Hervé Guillard, Ali Elarif, Boniface Nkonga.

In order to avoid some mesh singularities that arise when using quadrangular elements for complex geometries and flux aligned meshes, the use of triangular elements is a possible option that we have studied in the past years. However due to the appearance of fourth order terms in the PDE systems that we are interested in, pure Galerkin methods require the use of finite element methods with C^1 continuity. The PhD thesis of Ali Elarif that has begun in october 2017 is devoted to the study of these methods for complex PDE models encountered in plasma physics. Relying on the work previously done on steady elliptic PDE, this year we applied these finite element methods to some evolution problems like the incompressible Navier-Stokes and MHD equations in stream-function formulation. Error estimates in H^2 norms have been obtained using standard finite element techniques. The simulation of some instabilities encountered in plasma physics have been done with very satisfactory results.

4.13. Modelling of acoustic streaming

Participants: Hervé Guillard, Argyris Delis [TUC, Crete].

Acoustic streaming is a particularly interesting example of the interaction of phenomena occurring on two different time scales. From a practical point of view, it is mainly used to generate a slow motion in micro-fluidic devices by means of high frequency acoustic sources. Modelling of these interaction is a challenge : taking into account the high frequency phenomena is prohibitively expensive but on the other hand, there is no universal agreement on existing averaged models. In order to have reference simulations, we have constructed a numerical code solving the compressible Navier-Stokes equations with high-order accuracy using compact schemes. Comparison with asymptotic analytical results has been done and shows that the code is able to simulate acoustic waves propagation in a stable way on long time scale, a property that is essential for the study of this phenomenon.

4.14. Mortar finite element methods

Participants: Hervé Guillard, Francesca Rapetti.

Hermite-Bezier finite element modeling is the standard method used to discretize the MHD equations in codes such as JOREK. This finite element family allows for an accurate description of the magnetic topology using flux aligned grids where the iso-parametric curved elements match the magnetic flux level sets. However, the description of complex material geometries is difficult with this family of finite element. We have begun to study the use of discretization methods using overlapping meshes where one mesh is composed of quadrangular Hermite-Bezier finite element while the second one is made of triangular elements.

4.15. Collisions in gyrokinetic equation

Participants: Afeintou Sangam, Vladimir T. Tikhonchuk.

Charged particles in plasma in strong magnetic fields undergo a complicated motion, which is a combination of a fast cyclotron gyration around the magnetic field lines and a relatively slow dynamics along and across the magnetic field lines. Gyrokinetic equations, devised to describe plasma under such conditions, eliminate the fast cyclotron gyration from the equation of motion, thus reducing the space-velocity phase space dimension from six to five.

Originally, the gyrokinetic formulation was devised for a collisionless plasmas. The quest for retaining collisions in gyrokinetic equations is ongoing. Collisions are important if one wants to describe the transport properties of a magnetized plasma on a macroscopic level. A description of the transport of energy and momentum was proposed in Refs. [18], [20], [19], [22], [21]. However, mathematical description of collisions in these works is too complicated for numerical implementation. We develop a simplified description of collision operators in the gyrokinetic formulation that preserve the pertinent conservation features and suitable for numerical modeling. A comparison of these operators with several test cases is under investigation.

4.16. Singular solutions of dispersive systems

Participants: S. Gavriluk, B. Nkonga, K-M Shyue, L. Truskinovsky.

We study a dispersive regularization of p-system. The governing equations are the Euler- Lagrange equations for a Lagrangian depending not only on the velocity and density, but also on the first material derivative of density. Such regularization arises, in particular, in the modeling of waves in solids, in bubbly fluids as well as in the theory of water waves. We show that such terms are not always regularizing. The solution can develop shocks even in the presence of dispersive terms. In particular, we construct such a shock solution that connects a constant state to a periodic wave train. The corresponding shock speed coincides with the velocity of the wave train. The generalized Rankine-Hugoniot relations (jump relations) are also obtained. The numerical evidence of the existence of such shocks is demonstrated in the case of the Serre-Green-Naghdi equations describing long surface water waves. In particular, it has been shown that such waves can dynamically be formed

4.17. A path conservative finite volume method for a shear shallow water model

Participants: P. Chandrashekar, B. Nkonga, A. K. Meena, A. Bhole.

The shear shallow water model provides a higher order approximation for shallow water flows by including the effect of vertical shear in the model. This model can be derived from the depth averaging process by including the second order velocity fluctuations, which are neglected in the classical shallow water approximation. The resulting model has a non-conservative structure, which resembles the 10-moment equations from gas dynamics. This structure facilitates the development of path conservative schemes and we construct HLL, 3-wave and 5-wave HLLC-type solvers. An explicit and semi-implicit MUSCL-Hancock type second order scheme is proposed for the time integration. Several test cases including roll waves show the performance of the proposed modeling and numerical strategy.

4.18. Full MHD Modeling of Shattered Pellet Injection

Participants: B. Nkonga, P. Chandrashekar, A. Bhole.

To avoid disruptions, the first thing to do is to operate as far as possible from disruptions operational limits. It means that plasma scenarios must be designed taking these limits into account. The challenge is to deal with peeling-ballooning instabilities called Edge Localized Modes (ELMs) which are characterized by the quasi-periodic relaxation of the pressure pedestal profile which results in the expelling of particles and energy from the bulk plasma to the edge. Injecting of impurities is one of the solutions to change the pedestal profile and mitigate MHD instabilities. The current design of the ITER DMS(Disruption Mitigation System) is a hybrid system using Massive Gas Injection (MGI) and Shattered Pellet Injection (SPI), methods which have demonstrated their efficiency on current tokamaks (JET, DIII-D, ...). Considering that the plasma is composed of impurities, main ion core and set of electrons, premixed "Full MHD" formulation has been proposed. This model assumes that, for any control volume, the plasma is locally neutral and at the thermal and coronal equilibrium. Properties of this model are under analysis, according to the tabulated equation of state. A numerical approximation in the Jorek Code is also under progress. This work has been done in the context of the JET program 2019.

5. Partnerships and Cooperations

5.1. National Initiatives

5.1.1. ANR Sistem

Member of the ANR SISTEM, Oct. 2019 - Sept. 2023 coordinated by the M2P2 Institute of Aix-Marseille Univ. "SIMulations with high-order schemes of tranSPort and Turbulence in tokaMak" programme Modeles numeriques 2019

- Participants: Francesca Rapetti, Blaise Faugeras, Didier Auroux, Jacques Blum, Cédric Boulbe

Contact: F. Rapetti

5.2. European Initiatives

5.2.1. FP7 & H2020 Projects

EuroFusion Consortium

CASTOR participates to the following EuroFusion consortium projects :

EUROfusion WPCD (Working Package Code Development):

- EWE-2: Enabling Workflow Exploitation Area - Enabling the exploitation of the equilibrium reconstruction and MHD stability workflow (participation)
- WDEV-2: Workflow Development Area - Free boundary equilibrium and feedback control (participation and coordination)

EuroFusion Enabling Research CfP-AWP19-ENR-01, Strengthening the non-linear MHD code JOREK for application to key questions of the fusion roadmap.

EUROfusion WPSA(Work Package JT-60SA) 2018-2010

5.3. International Initiatives

5.3.1. Informal International Partners

The team collaborates with TUC (Technical University of Crete, Prof. Argyris Delis) on the modelling of acoustic streaming phenomena. In this framework, Argyris Delis has visited the Castor team in November 2019.

6. Dissemination

6.1. Promoting Scientific Activities

6.1.1. Journal

6.1.1.1. Member of the Editorial Boards

- J. Blum is member of the editorial board of the Journal Scientific Computing.
- F. Rapetti is member of the editorial board of the Advances in Computational Mathematics (ACOM) journal by Springer
- C. Boulbe is managing editor of the SMAI Journal of Computational Mathematics

6.1.1.2. Reviewer - Reviewing Activities

- H. Guillard has been reviewer for the Journal of Computational physics, Computers and Fluids and International Journal for Numerical methods in Fluids.

6.1.2. Invited Talks

- F. Rapetti: Keynote speaker at the Enumath conference (Egmond aan Zee), oct 2019, "High-order Whitney forms on simplices"

6.1.3. Leadership within the Scientific Community

- H. Guillard is coordinator of the topic "Turbulence and transport of edge plasma" within the Fédération FR-FCM

6.2. Teaching - Supervision - Juries

6.2.1. Teaching

Licence : F. Rapetti, Mathématiques 2,30h équivalent TD, L2, Université Cote d'Azur, France
 Master : F. Rapetti, Méthodes numériques, 70h équivalent TD, M1, Université Cote d'Azur, France
 Ecole d'ingénieur, C. Boulbe, Analyse Numérique 2, 45 équivalent TD, niveau L3, Université Cote d'Azur
 Ecole d'ingénieur, C. Boulbe, Analyse numérique 1, 71h équivalent TD, niveau L3, Université Cote d'Azur
 Ecole d'ingénieur, C. Boulbe, Algèbre linéaire et Scilab, 26h équivalent TD, Université Cote d'Azur
 Ecole d'ingénieur, C. Boulbe, Projet 1, 41h équivalent TD, Université Cote d'Azur
 Licence: A. Sangam, Mathématiques Fondements 1, 60h, Semestre 1 de la Licence, Université Nice Sophia Antipolis, France
 Licence: A. Sangam, Méthodes Mathématiques - Approche Continue, 30h, Semestre 1 de la Licence, Université Nice Sophia Antipolis, France
 Licence: A. Sangam, Mathématiques Compléments 1, 5h, Semestre 1 de la Licence, Université Nice Sophia Antipolis, France
 Licence: A. Sangam, Mathématiques Fondements 2, 6h, Semestre 2 de la Licence, Université Nice Sophia Antipolis, France
 Licence: A. Sangam, Analyse 2, 2h, L2, Université Nice Sophia Antipolis, France
 Licence: A. Sangam, Analyse Numérique, 70h, L3, Université Nice Sophia Antipolis, France
 Licence: A. Sangam, Calcul Différentiel, 20h, L3, Université Nice Sophia Antipolis, France
 Ecole d'ingénieur/Master: B. Nkonga, Méthode des éléments finis, 24h, M2, Polytech Nice Sophia, France
 Ecole d'ingénieur/Master: B. Nkonga, Eléments finis mixtes, 24h, M2, Polytech Nice Sophia, France

6.2.2. Supervision

PhD : Xiao Song, Model-based Control-oriented Scenario Construction in Tokamaks, Université Cote d'Azur, 6 décembre 2019, Blaise Faugeras, Holger Heumann
 PhD in progress : Ali Elarif, "Simulation numérique des instabilités magnétohydrodynamique dans les Tokamaks", October 2017, Hervé Guillard

6.2.3. Juries

- Hervé Guillard has been part of the jury for the Phd defence of Corentin Prigent, "Etude numérique et modélisation du modèle d'Euler bi-température : point de vue cinétique", Bordeaux University, 24/10/2019.
- Hervé Guillard was referee for the Phd jury of Clément Colas, "Formulation intégrale implicite pour la modélisation d'écoulements fluides en milieux encombrés", AMU University, 14/11/2019.
- Hervé Guillard has been part of the jury for the Phd defence of Quentin Carmouze, "Modélisation et simulation numérique des écoulements diphasiques denses et dilués", Nice University, 28/12/2019.
- F. Rapetti: Juan Antonio Soler Vasco, Univ. Aix-Marseille, Sep. 2019.
- F. Rapetti: Anouk Nicolopoulos-Salle, Univ. Sorbonne Paris, Déc. 2019.
- B. Faugeras, H. Heumann, H. Guillard and J. Blum: Xiao Song, Université Cote d'Azur, Dec. 2019

7. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

- [1] A. ALONSO RODRÍGUEZ, F. RAPETTI. *Some remarks on spanning families and weights for high order Whitney spaces on simplices*, in "Computers and Mathematics with Applications", November 2019, vol. 78, n^o 9, pp. 2961-2972 [DOI : 10.1016/J.CAMWA.2019.03.006], <https://hal.archives-ouvertes.fr/hal-02411192>

- [2] A. BHOLE, B. NKONGA, S. L. GAVRILYUK, K. A. IVANOVA. *Fluctuation splitting Riemann solver for a non-conservative modeling of shear shallow water flow*, in "Journal of Computational Physics", 2019 [DOI : 10.1016/J.JCP.2019.04.033], <https://hal.archives-ouvertes.fr/hal-01877504>
- [3] J. BLUM, H. HEUMANN, E. NARDON, X. SONG. *Automating the design of tokamak experiment scenarios*, in "Journal of Computational Physics", October 2019, vol. 394, pp. 594-614 [DOI : 10.1016/J.JCP.2019.05.046], <https://hal.archives-ouvertes.fr/hal-02418396>
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