

# Application BASTRI

## Fiches Equipes

### MAKUTU (SR0903YR)

Modélisation et simulation de la propagation des ondes fondées sur des mesures expérimentales pour caractériser des milieux géophysiques et héliophysiques et concevoir des objets complexes  
MAGIQUE-3D (SR0005GR) □ MAKUTU

**Statut:** Décision signée

**Responsable :** Helene Barucq

**Mots-clés de "A - Thèmes de recherche en Sciences du numérique - 2023" :** A3.4.6. Réseaux de neurones , A6.1. Outils mathématiques pour la modélisation , A6.1.1. Modélisation continue (EDP, EDO) , A6.1.4. Modélisation multiéchelle , A6.1.5. Modélisation multiphysique , A6.2. Calcul scientifique, analyse numérique et optimisation , A6.2.1. Analyse numérique des EDP et des EDO , A6.2.7. HPC , A6.3.1. Problèmes inverses , A6.3.4. Réduction de modèles , A6.5. Modélisation mathématique pour les sciences physiques , A6.5.1. Mécanique des solides , A6.5.4. Ondes

**Mots-clés de "B - Autres sciences et domaines d'application - 2023" :** B3. Environnement et planète , B3.3. Géosciences , B3.3.1. Terre, sous-sol , B4. Energie , B9.2.1. Musique, sons , B9.5.2. Mathématiques , B9.5.3. Physique , B9.5.5. Mécanique

**Domaine :** Santé, biologie et planète numériques

**Thème :** Sciences de la planète, de l'environnement et de l'énergie

**Période :** 01/02/2021 -> 31/12/2027

**Dates d'évaluation :** 01/12/2022

**Etablissement(s) de rattachement :** BORDEAUX INP, U. PAU (UPPA), CNRS, TOTALENERGIES

**Laboratoire(s) partenaire(s) :** LMAP (UMR5142)

**CRI :** Centre Inria de l'université de Bordeaux

**Localisation :** Université de Pau et Pays de l'Adour

**Code structure Inria :** 091069-0

**Numéro RNSR :** 202123948U

**N° de structure Inria:** SR0903YR

### Présentation

Numerical geosciences encompass a large variety of scientific activities tackling societal challenges like water resources, energy supply, climate change, etc. They are based upon observations, physical modeling and accurate mathematical formulations. The tremendous progresses of scientific computing have allowed the addition of extensive numerical simulations which provide tools based on wave measurements to study and possibly monitor complex environments that are otherwise difficult to probe and even fathomless e.g. the subsurface or the interior of

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### En savoir plus

- Site de l'équipe
- Site sur [inria.fr](http://inria.fr)
- Derniers Rapports d'Activité : 2021 , 2022 , 2023

### Documents sur la structure

- [Intranet](#)
- [Privés](#)

### Décisions

- **14675** (02/02/2021) : création
- **15284** (13/01/2022) : modification
- **15815** (29/11/2022) : prolongation
- **16820** (13/02/2024) : prolongation

### Localisation

- **Adresse postale :** Université de Pau et des Pays de l'Adour Avenue de l'Université BP 576 64012 PAU cedex France
- **Coordonnées GPS :** 43.1849, 0.22

stars. Bridging the gap between experimental measurements and numerical simulations is an important objective of Makutu, which will pursue a balance between accuracy and efficiency depending on the application domains in consideration. A common strategy will be to develop frugal models using mathematical methods (asymptotic methods, artificial boundary conditions, reduction methods...), and efficient numerical schemes (in time and harmonic domains, with analytical and high order numerical methods). Makutu proposes a research program to develop numerical software packages for retrieving shapes and/or physical properties of complex media with a particular focus on the **Earth and its natural reservoirs**. For this, the team is collaborating with experimental geophysicists from the LFCR (Laboratory of Complex Fluids and their Reservoirs, UPPA) who help to assess the impact of parameters on the wave propagation. In addition to geophysical setting, Makutu's research program includes two other topics: **solar imaging** and **musical acoustics**. For solar imaging, modeling is of great importance and the team is working with different equations in a new mathematical formalism. New simulation codes are under development with a long-term view to solve inverse problems. Given the similarities that exist between seismic and solar imaging methods, software development is carried out in-house using many of the skills acquired by the team in geophysical imaging. Regarding modeling of musical instruments, the size of the objects and the wavelengths considered are different from geophysical or solar contexts, but similar physical principles and theoretical aspects of models and numerical methods are applicable. Last but not least, parameter reduction and great precision required in the simulation and the possibility to easily

compare numerical and experimental data make them an ideal topic to develop new research related to modeling and simulating wave propagation. To address the above research agenda, the team gathers applied mathematicians and acousticians who have long working experience in wave propagation. The team is jointly shared by the University of Pau and Pays de l'Adour (UPPA) and Inria. The majority of Makutu's members are located in Pau. The team is therefore attached to LMAP (Mathematics and Applications Laboratory in Pau, UMR CNRS 5142). However, some members of the team are located in Talence, in the Inria building of the Bordeaux campus. The choice of Makutu's principal location in Pau is fully justified by the long-term involvement of the city of Pau in Geosciences, which offers an important network of companies working in the geo-resources sector. In particular, the company Total is our main industrial partner with whom we aim at developing activities on energy transition.

### Axes de recherche

Makutu organizes its research program from in-house accurate solution methodologies for simulating wave propagation in realistic scenarios to various applications involving transdisciplinary efforts. Performing simulations of real-world phenomena is an ultimate endeavor by all numerical scientists. To achieve this, one needs real data and advanced mathematical models and high-order numerical schemes that are compatible with high-performance computing architectures.

To obtain real data, in addition to its current collaborations with scientists both from Academia and Industry, Makutu is developing a new branch of research activities by carrying out its own laboratory measurements. The desire to carry out its own measurements is motivated by the need to solve problems whose increasing complexity involves a large number of physical parameters that need to be calibrated. For instance, in order to take into account porosity, parameters such as viscosity, attenuation, thermodynamic effects, etc., must be integrated, and their impact must be properly analyzed before considering using them to characterize the propagation media. This constitutes a clear step ahead for Makutu, and opens up new prospects of contributing to the characterization of very complex media based on wave field measurements.

Regarding the development of numerical schemes, Makutu is developing high-order Discontinuous Galerkin (DG) methods and high-order time schemes. Recently, the team has launched a new research project on space-time integration for seismic waves, in partnership with Total. The coupling of DG methods with other techniques of discretization is also under consideration. Trefftz-DG and Hybridizable DG methods are currently developed both for poro-elastic waves and electromagnetic waves. HDG and HDG+ formulations are also under study for helioseismology.

The research activities of members of Makutu share a common theme of using numerically computed wavefield measurements to reconstruct the propagation medium they passed through before recording. The medium can be reconstructed by identifying either the physical parameters or the geometrical parameters that characterize it. In each case, the next step is to solve an inverse problem that is non-linear and ill-posed. To solve it, Makutu is focusing on the Full Waveform Inversion (FWI), which is a high-definition imaging method widely used in the field of geophysics.

## Relations industrielles et internationales

Makutu relies on strong collaborations and partnerships with various institutions including (a) local industry (TOTAL, RealTimeSeismic), (b) national research centers (ONERA), and (c) international academic partnerships (e.g. Interdisciplinary Research Institute for the Sciences (IRIS) at California State University, Northridge, USA; University of Pays Basque and Basque Center of Applied Mathematics at Bilbao, Spain; University of California at Berkeley, Lawrence Berkeley National Laboratory, Max Planck Institute at Göttingen).