CIC bioGUNE

Research Line II:

Multiphysics, Inversion, and Petroleum

David Pardo

Research Professor at BCAM

***Team:** D. Pardo, I. Garay, I. Andonegui, J. Álvarez*

***Collaborators:** P. de la Hoz, M. Paszynski, L.E. García-Castillo, I. Gómez, C. Torres-Verdín*

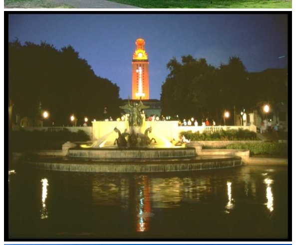
May 11th, 2009

me, myself, and I

Professional Career of David Pardo

Univ. of the Basque Country.
Bachelors in Applied Mathematics
Acquired Basic Knowledge in Mathematics.
4 years (1996-2000).

ICES, UT Austin.
Ph.D. in Computational and Applied Mathematics
Acquired Expertise in Computer Simulations.
4 years (2000-2004).



Petroleum Engineering, UT Austin.
Postdoctoral Fellow and Research Associate in Engineering.
Simulated Real-World Engineering (Oil-Industry) Problems.
4 years (2004-2008).

BCAM.
Research Professor in Applied Mathematics.
Coordinate a Research Team in Computer Based Simulations.
8 years (2008-2015).

overview

1. **Motivation (Oil-Industry and Medical Applications).**
2. **Main Scientific Objectives: Joint Multiphysics Inversion.**
3. **Main Challenges and State-of-the-Art.**
4. **Method: Parallelization + hp-FEM + Automatic Grid Refinements + Goal-Oriented Methods + Fourier Method + De Rham Diagram.**
5. **Numerical Results.**
6. **Conclusions.**

motivation and objectives

Seismic Measurements

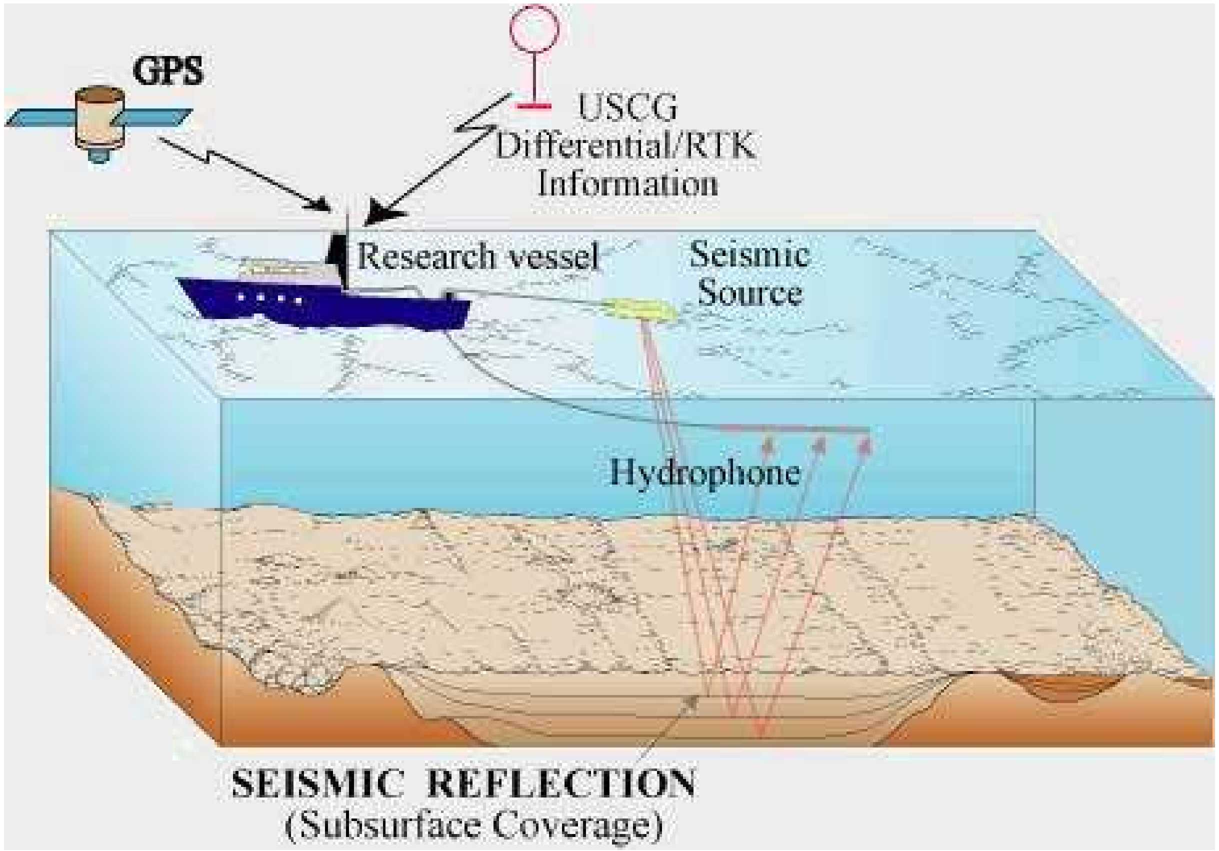


Figure from the USGS Science Center for Coastal and Marine Geology

motivation and objectives

Marine Controlled-Source Electromagnetics (CSEM)

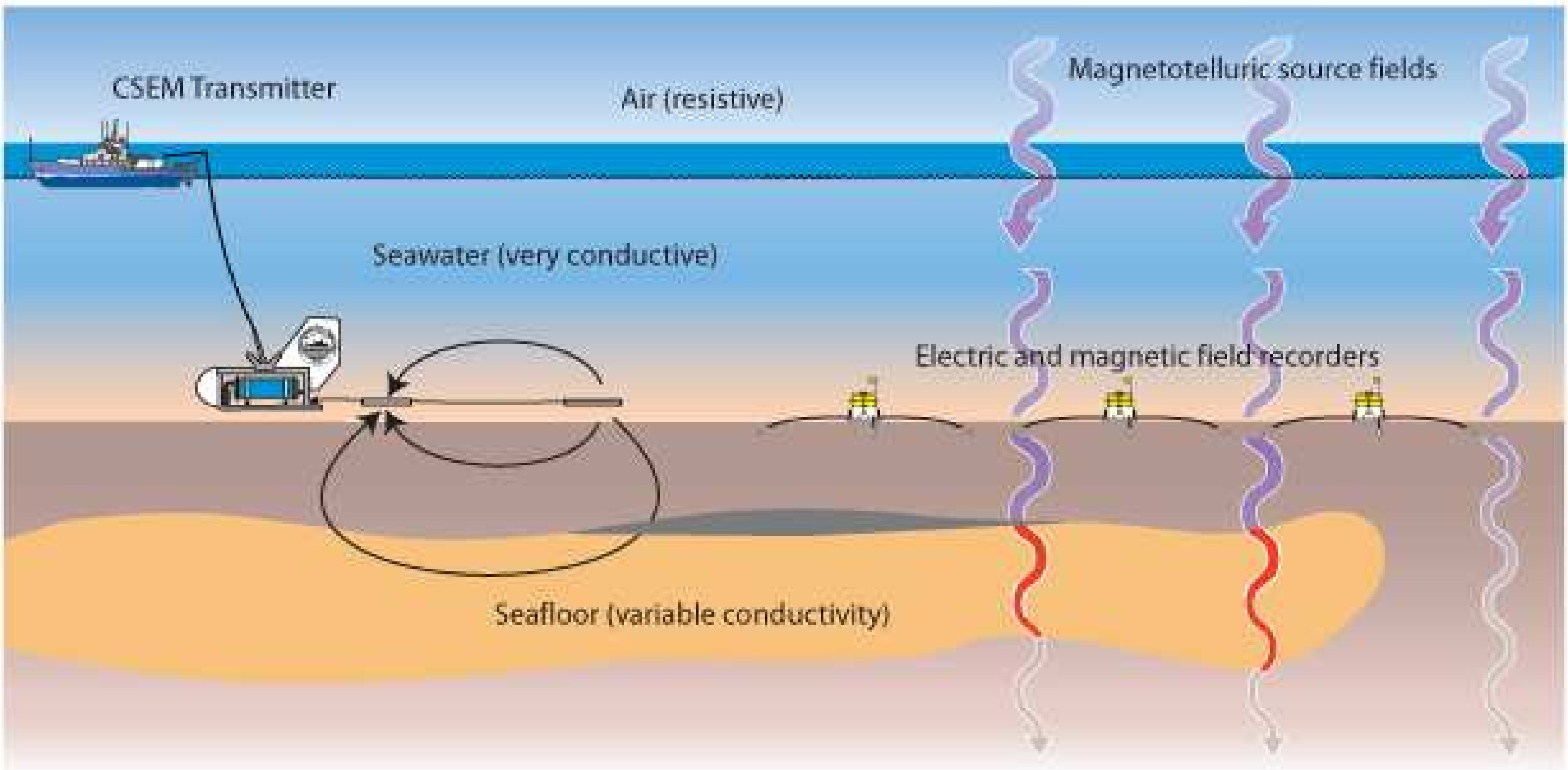
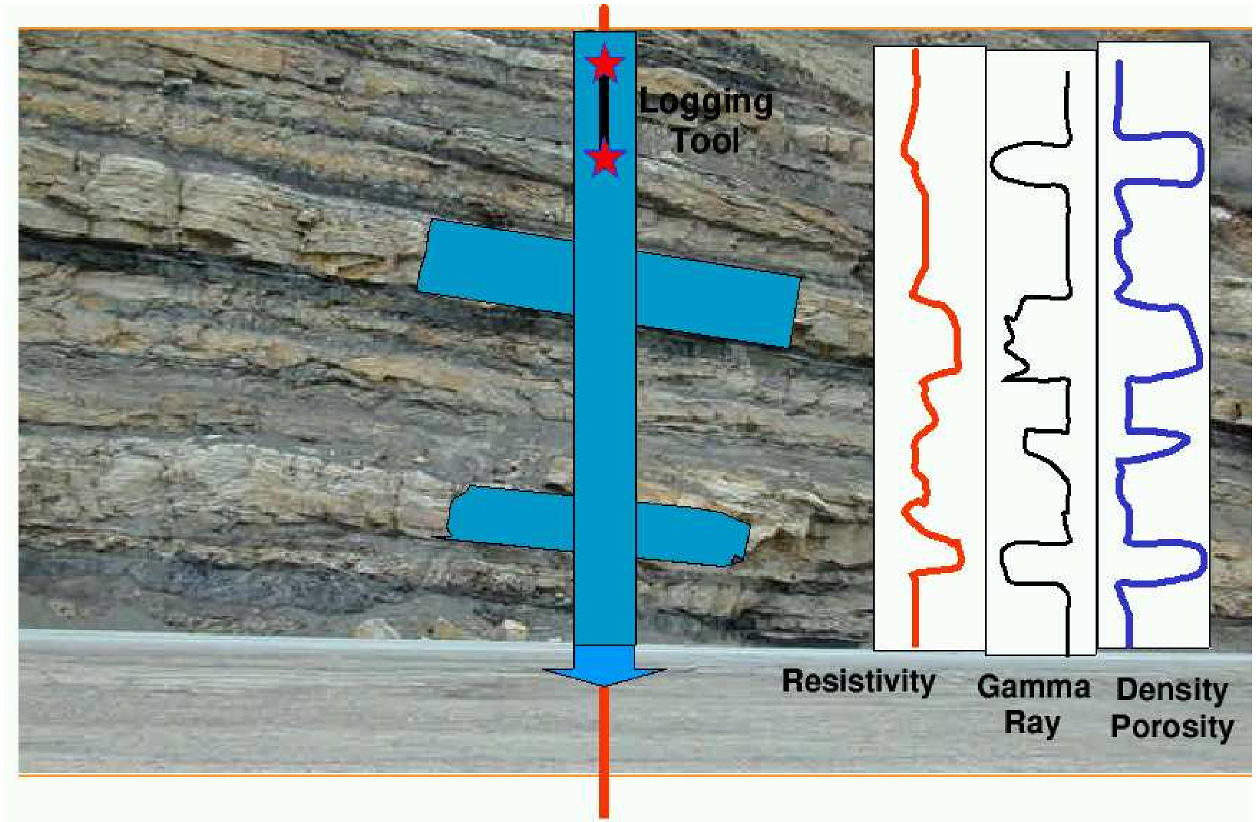


Figure from the UCSD Institute of Oceanography

motivation and objectives

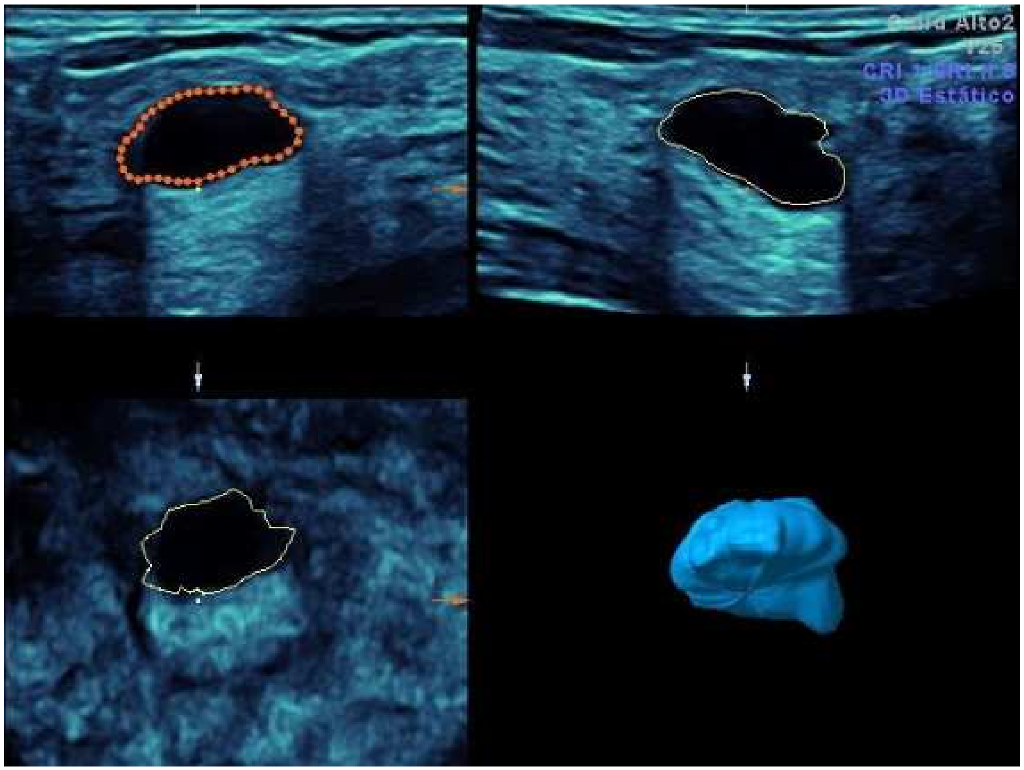
Multiphysics Logging Measurements

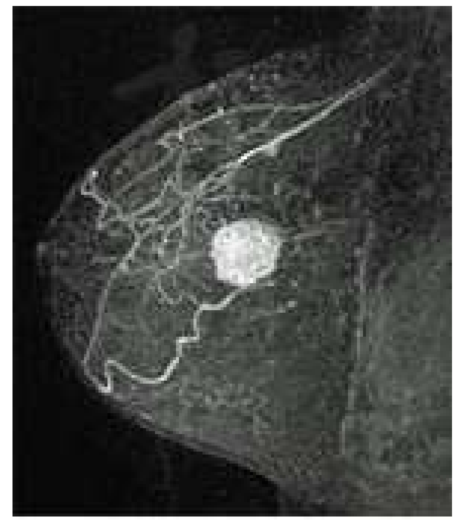


OBJECTIVES: To determine payzones (porosity), amount of oil/gas (saturation), and ability to extract oil/gas (permeability).

motivation and objectives

Joint Multiphysics Inversion (Medical Application)



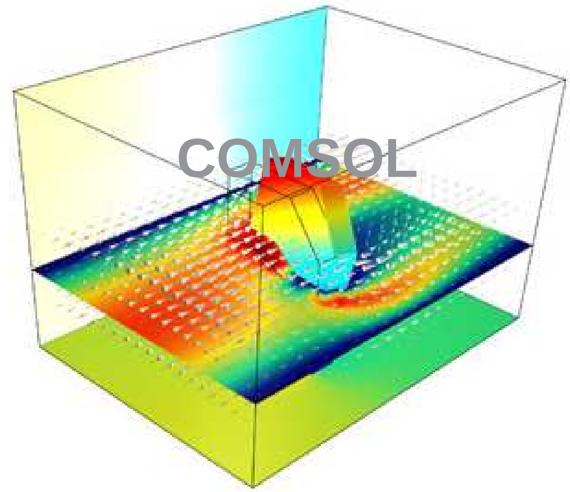


Detection of breast cancer using an ecography vs. MRI.

main challenges

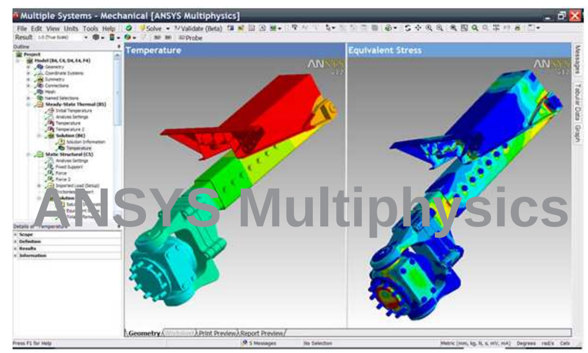
- **Mathematical challenges:**
  - Inverse problems are non-unique and ill-posed.
  - Stability and convergence properties of some multiphysics couplings may be unknown.
  - Choice of multiphysic couplings may affect performance.
  - Solutions corresponding to different physical phenomena may live in different spaces.
- **Physical challenges:**
  - Multiphysics couplings are possibly unknown/uncertain.
  - Possibly complex non-linearities and/or time-dependant phenomena.
- **Engineering challenges:**
  - We need goal-oriented algorithms, automatic grid generation/refinements (mesh-based methods), validation and verification (reliability).
- **Computer sciences challenges:**
  - There is a need for 3D computations (complex geometries, CPU time and memory consumption), parallelization, visualization, and efficient algorithms.

state-of-the-art



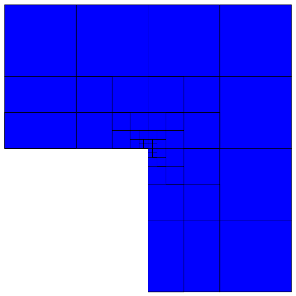
Available Commercial Software:

- COMSOL (structural, thermal, electromagnetics, chemichal, acoustics, heat transfer, etc.).
- ANSYS multiphysics (structural, thermal, fluid and electromagnetism).
- CFD-ACE+ (flow, heat transfer and turbulence) and CFD-FASTRAN (aerodynamic and aerothermodynamic).
- Other such as FlexPDE, LS-DYNA, NEi Nastran, IDC-SAC, OOFELIE, etc.



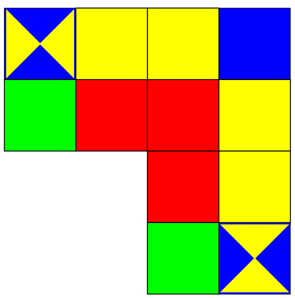
A large amount of commercial and non-commercial software for solving multiphysics problems has been generated during the last decade.

method: hp finite element method



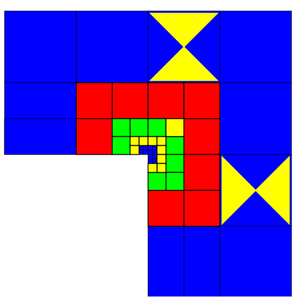
The h-Finite Element Method

1. Convergence limited by the polynomial degree, and large material contrasts.
2. Optimal h-grids do NOT converge exponentially in real applications.
3. They may “lock” (100$\%$ error).



The p-Finite Element Method

1. Exponential convergence feasible for analytical (“nice”) solutions.
2. Optimal *p*-grids do NOT converge exponentially in real applications.
3. If initial *h*-grid is not adequate, the *p*-method will fail miserably.



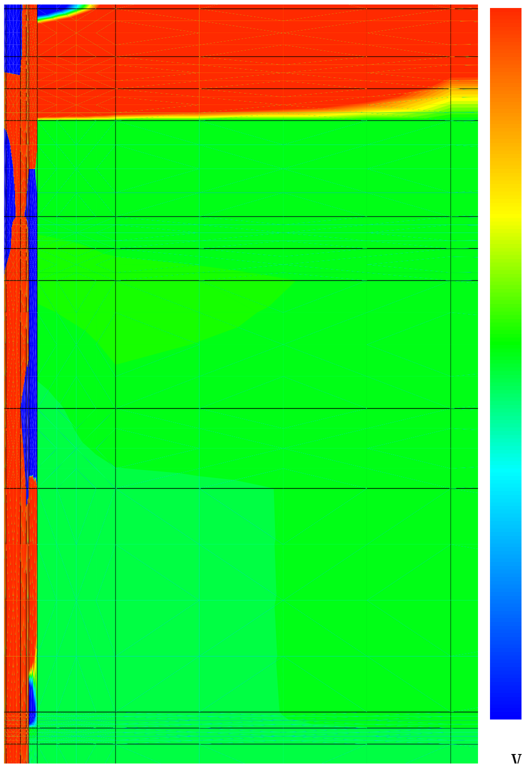
The hp-Finite Element Method

1. Exponential convergence feasible for ALL solutions.
2. Optimal *hp*-grids DO converge exponentially in real applications.
3. If initial *hp*-grid is not adequate, results will still be great.

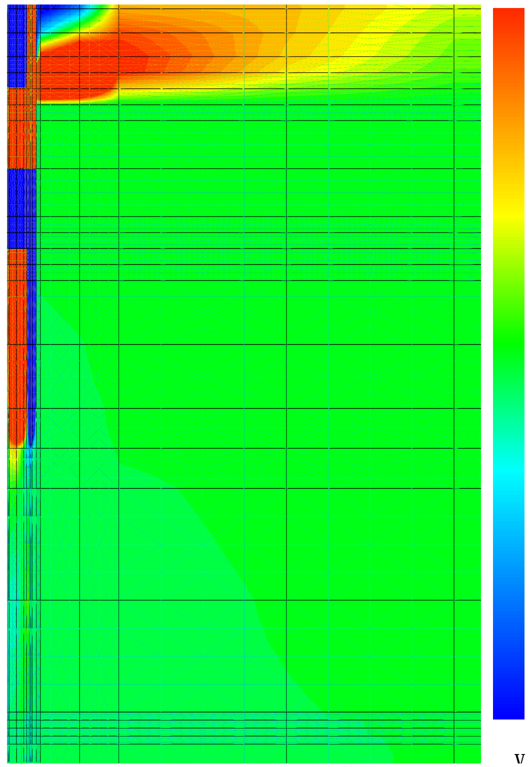
method: hp goal-oriented adaptivity and solver

Goal-Oriented Adaptivity (solve the adjoint problem, and use the representation theorem of the quantity of interest L(Ψ))

CONTRIBUTION TO L(Ψ) - COARSE GRID -



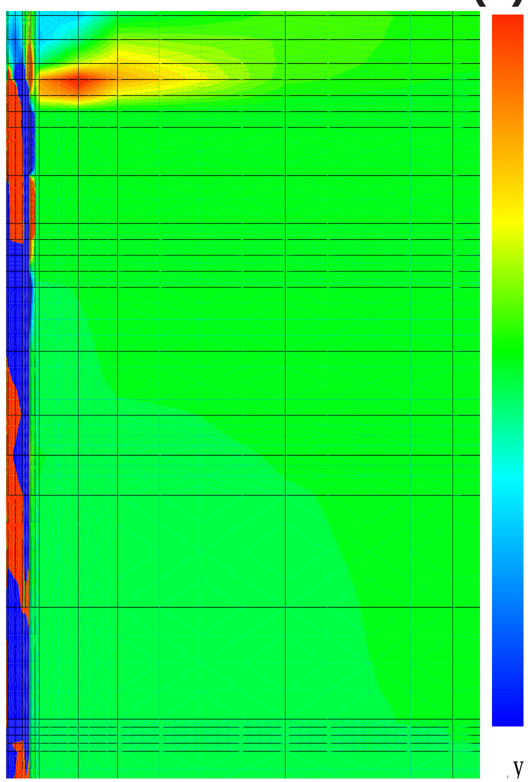
CONTRIBUTION TO L(Ψ) - FINE GRID -



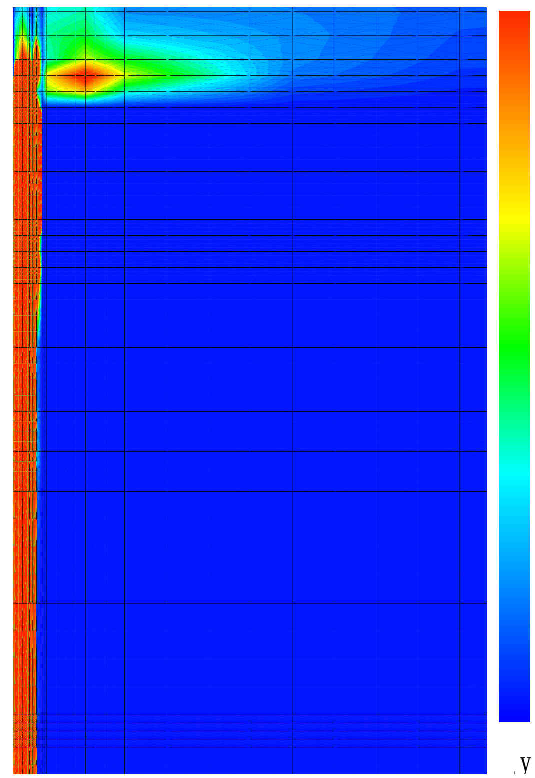
method: hp goal-oriented adaptivity and solver

Goal-Oriented Adaptivity (solve the adjoint problem, and use the representation theorem of the quantity of interest L(e))

CONTRIBUTION TO L(e)

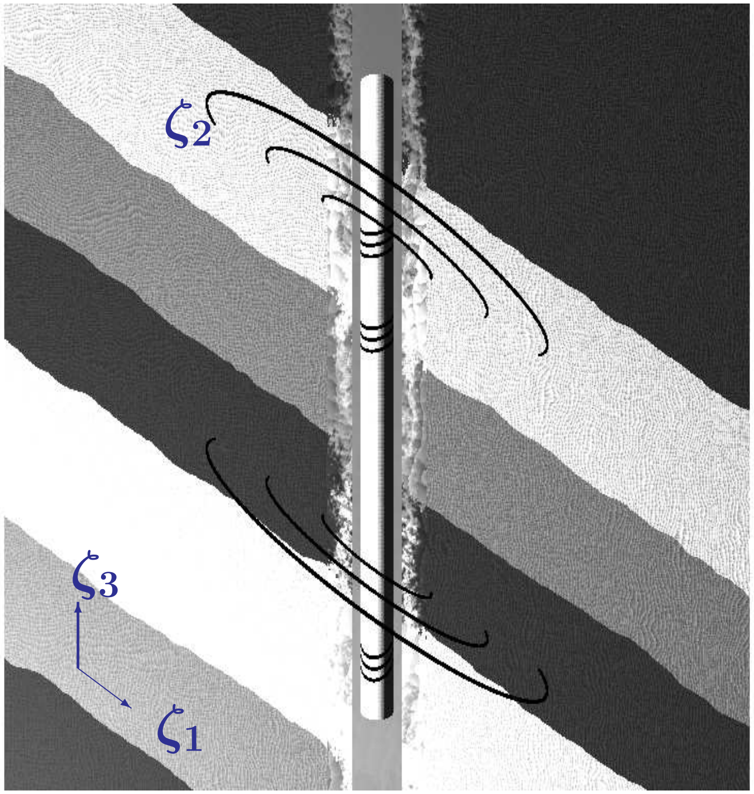


CONTRIBUTION IN ABS VALUE TO L(e)



method: Fourier finite element method

Non-Orthogonal System of Coordinates



Fourier Series Expansion in ζ_2

DC Problems: $-\nabla\sigma\nabla u = f$

$$u(\zeta_1,\zeta_2,\zeta_3) = \sum_{l=-\infty}^{l=\infty} u_l(\zeta_1,\zeta_3)e^{jl\zeta_2}$$

$$\sigma(\zeta_1,\zeta_2,\zeta_3) = \sum_{m=-\infty}^{m=\infty} \sigma_m(\zeta_1,\zeta_3)e^{jm\zeta_2}$$

$$f(\zeta_1,\zeta_2,\zeta_3) = \sum_{n=-\infty}^{n=\infty} f_n(\zeta_1,\zeta_3)e^{jn\zeta_2}$$

Fourier modes $e^{jl\zeta_2}$ are orthogonal high-order basis functions that are (almost) invariant with respect to the gradient operator.

method: de Rham diagram

De Rham diagram

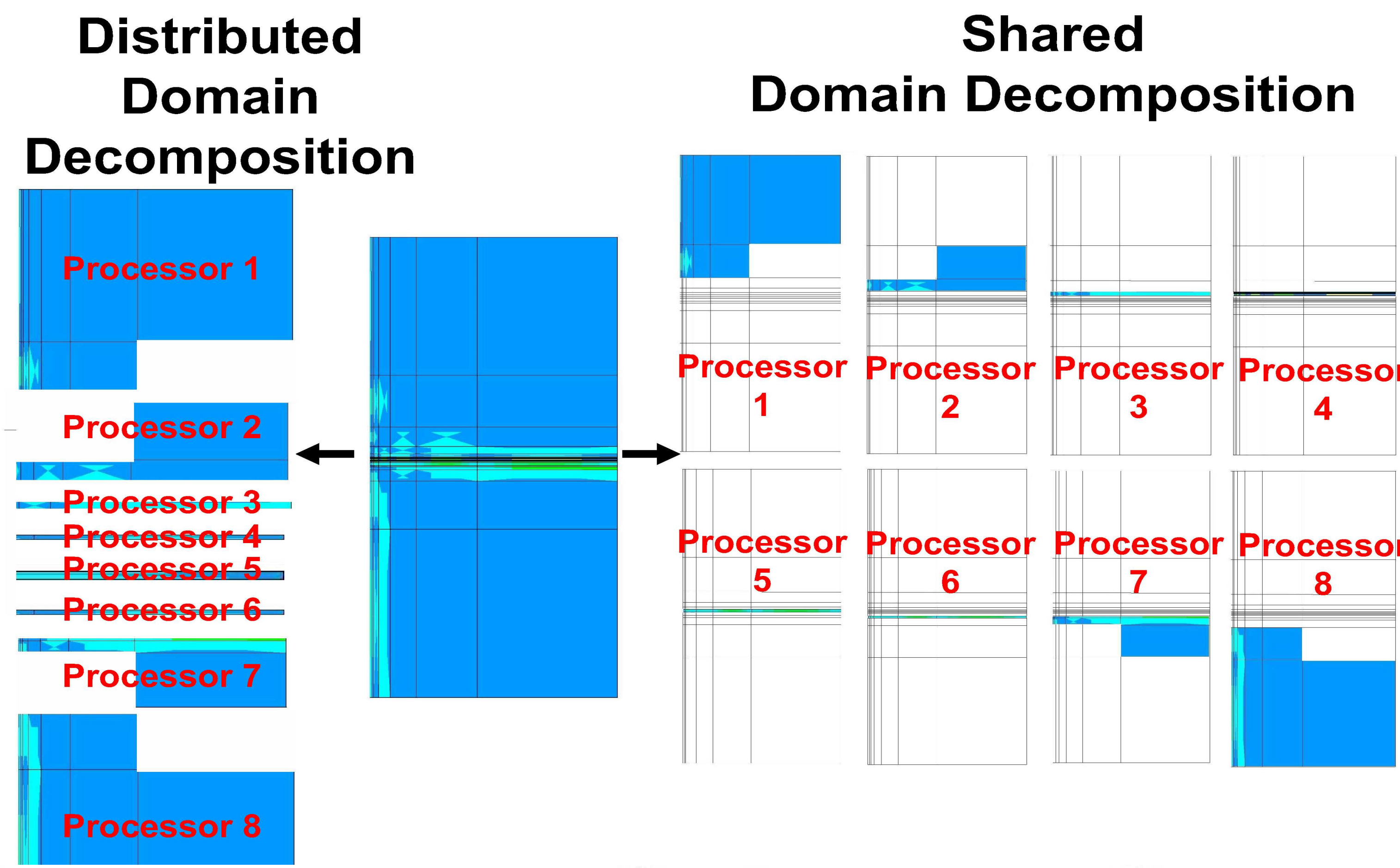
De Rham diagram is critical to the theory of FE discretizations of multi-physics problems.

$$
\begin{array}{ccccccccccc}
\mathbb{R} & \longrightarrow & W & \xrightarrow{\nabla} & Q & \xrightarrow{\nabla\times} & V & \xrightarrow{\nabla\circ} & L^2 & \longrightarrow & 0 \\
\downarrow id & & \downarrow \Pi & & \downarrow \Pi^{\mathrm{curl}} & & \downarrow \Pi^{\mathrm{div}} & & \downarrow P & & \\
\mathbb{R} & \longrightarrow & W^{\mathrm{p}} & \xrightarrow{\nabla} & \mathrm{Q}^{\mathrm{p}} & \xrightarrow{\nabla\times} & \mathrm{V}^{\mathrm{p}} & \xrightarrow{\nabla\circ} & W^{\mathrm{p}-1} & \longrightarrow & 0\,.
\end{array}
$$

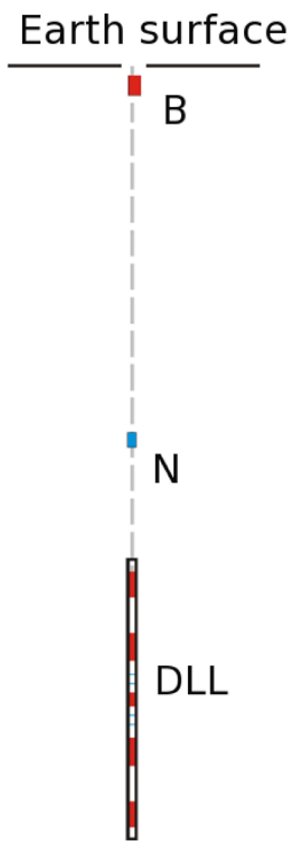
This diagram relates two exact sequences of spaces, on both continuous and discrete levels, and corresponding interpolation operators.

method: paralellization

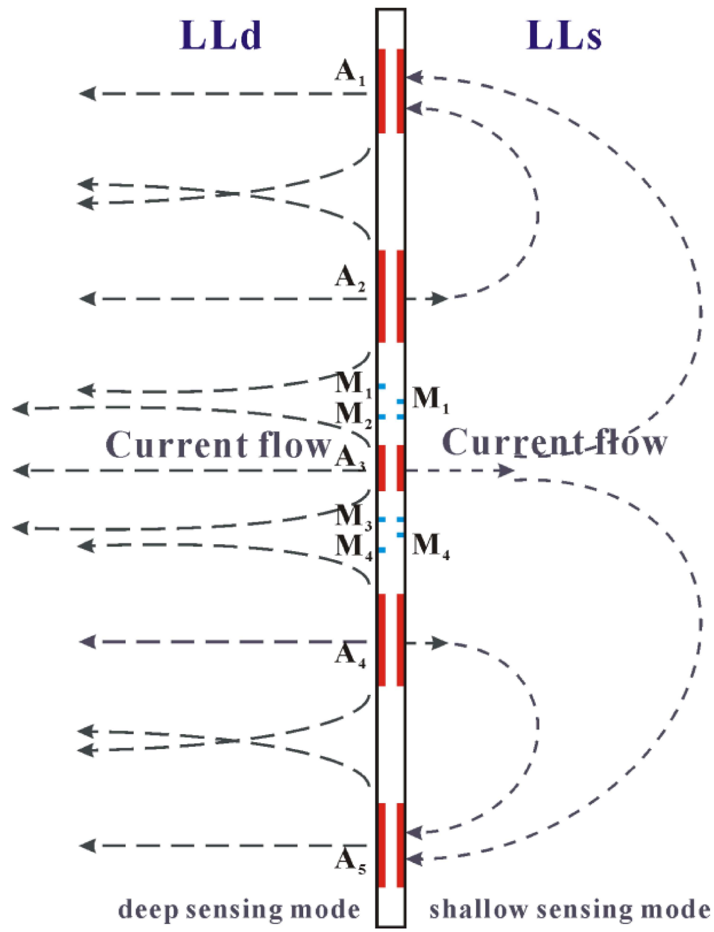
We Use Shared Domain Decomposition

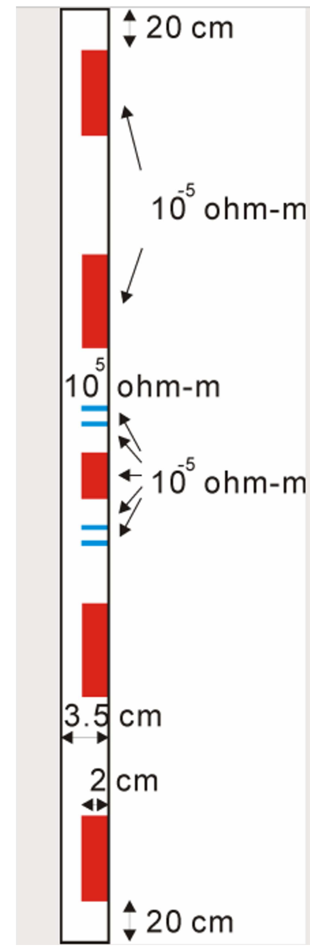


numerical results: electromagnetic applications



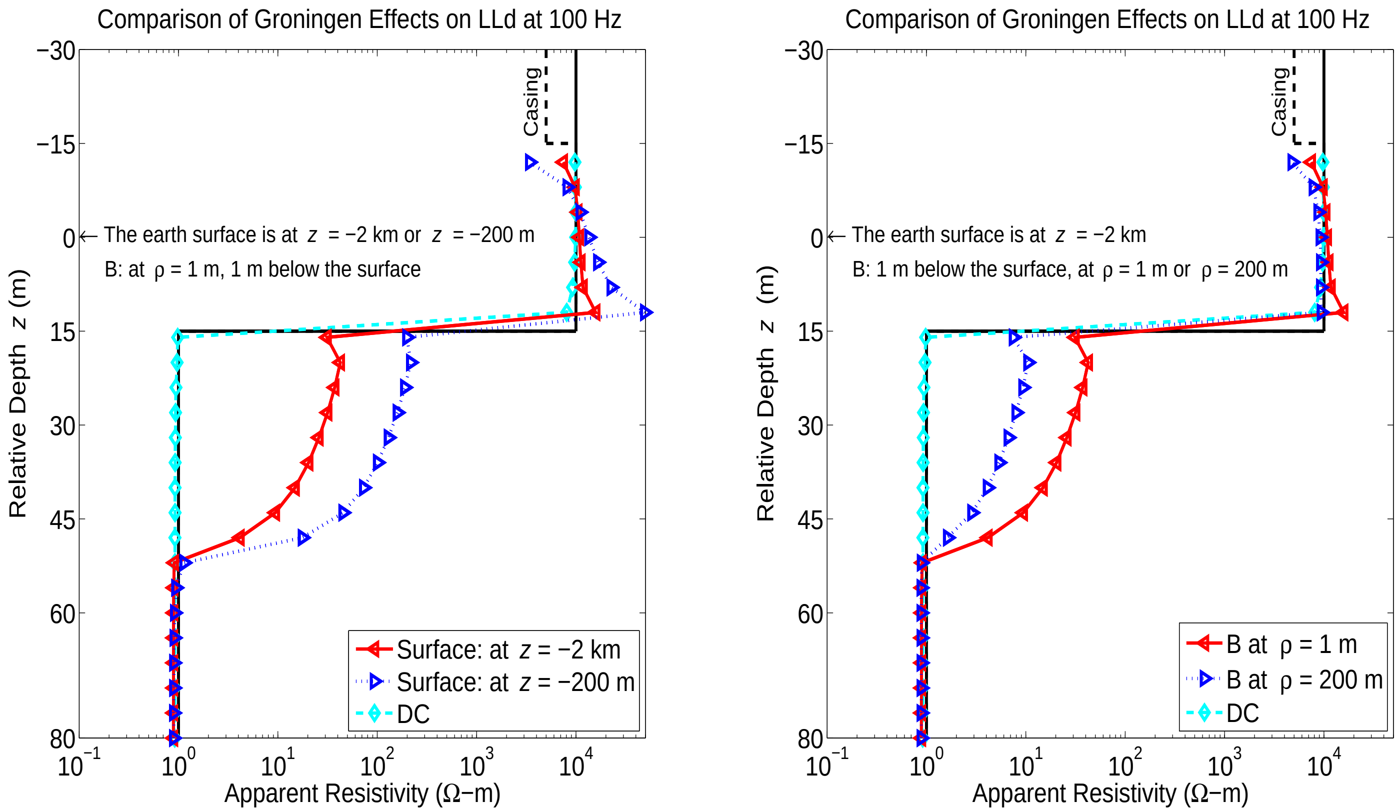
DLL Tool





numerical results: electromagnetic applications

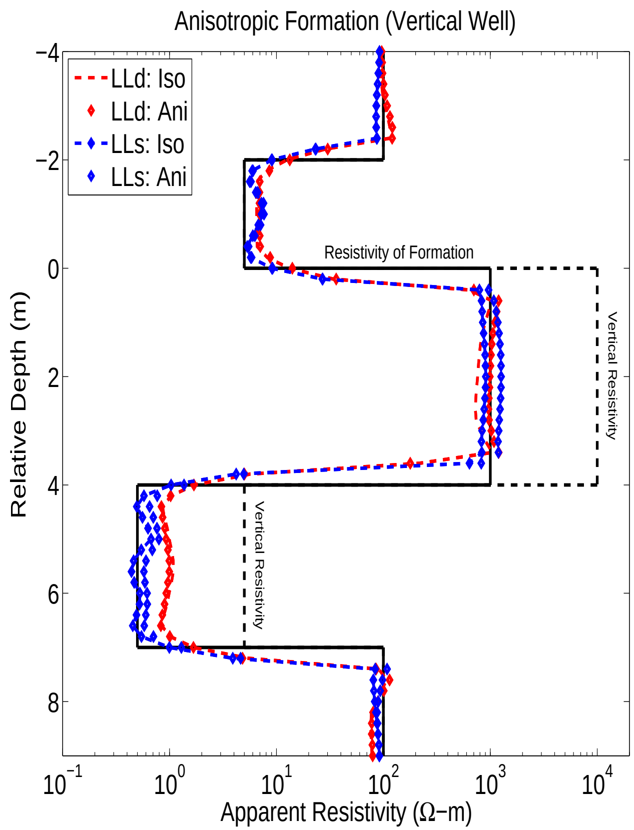
Groningen Effect

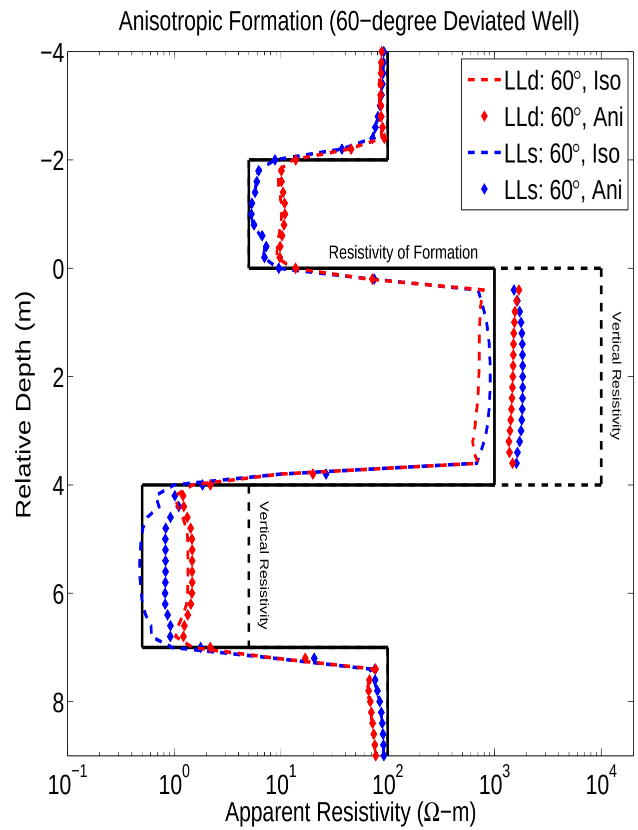


As we place the current return electrode B farther from the logging instrument, the Groningen effect diminishes

numerical results: electromagnetic applications

DC DLL in Deviated Wells

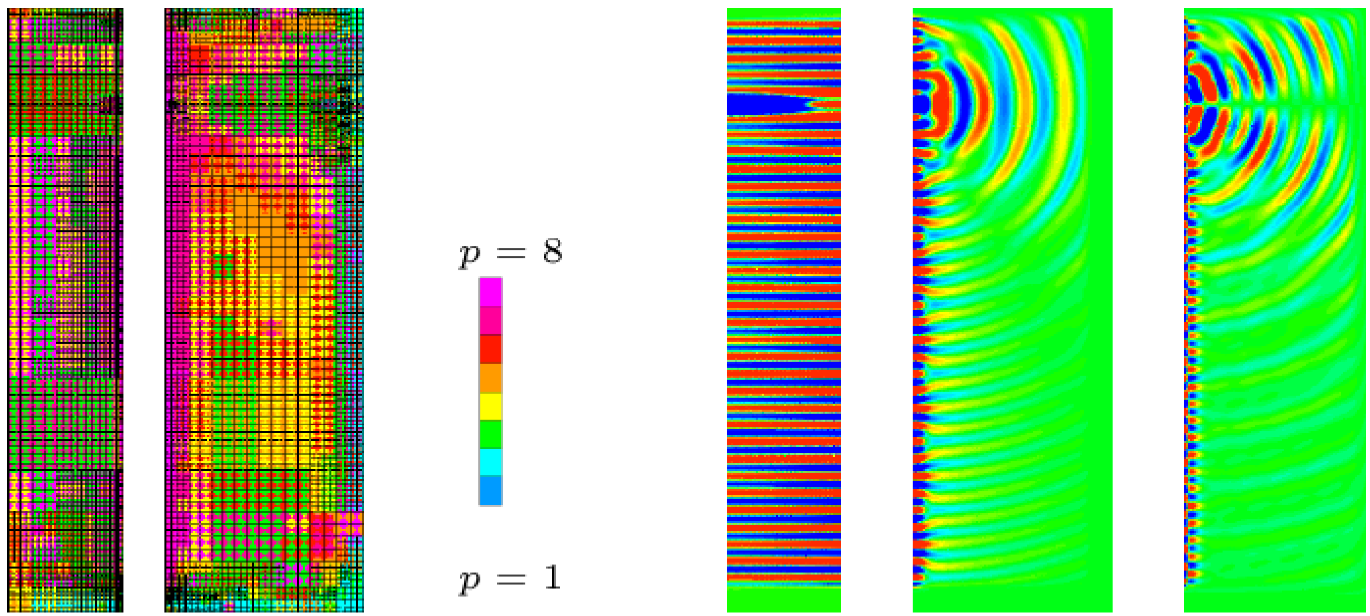




Anisotropy is better identified when using deviated wells

numerical results: acoustic applications

Final hp-grid and solution



acoustic hp-mesh | elastic hp-mesh | acoustic p_{acoust} | elastic u_r | elastic u_z

8 KHz, acoustics, open borehole setting (no logging instrument).

conclusions: team and collaborations

I. Garay

Development of algorithms for solving multiphysics inverse problems.

F. de la Hoz

Development of fast iterative solvers.

M. Paszynski

Parallel computations.

M.J. Nam

Simulations of resistivity logging instruments.

conclusions: team and collaborations

L.E. García-Castillo

Electromagnetic computations.

E. Pérez

Visualization.

I. Gómez

Three-dimensional computations.

C. Torres-Verdín

Contacts with the oil industry.

conclusions

- **We have recently created a research team working on advanced numerical analysis and computer based simulations of different physical phenomena.**
- **We are expanding our team to a size of 6-8 members to deal with more complex multi-phsyics problems. For that purpose, we are now looking for reserchers (Ph.D. students, and postdoctoral fellows).**
- **We are interested in solving multi-physics problems, inverse and optimization problems, and simulation problems with real-world applications.**
- **We are interested in collaborations with different research centers. For that purpose, we typically identify projects where all collaborators have an expertise on a particular area of the project to be developed.**