2018-00370 - PhD - Modeling and numerical simulation of acoustic wave propagation in the Sun

Level of qualifications required: Graduate degree or equivalent
Fonction: PhD Position

About the research centre or Inria department

Magic-3D was created to apply in different geophysics, and particular seismic wave propagation. First, advanced models have been developed in order to take into account the complexity of underlying phenomena. Second, these models can be applied to realistic cases that require the solution of large systems, which in turn require that numerical methods have been optimized.

Context

Scientific priorities: Multiscale everywhere
Scientific Research context:

Magique 3D has launched a collaboration with the team of Laurent Gizon of Max Planck Institute (Göttingen, Germany) for developing a joint simulation platform dedicated to helioseismology: imaging the Sun’s interior via the study of surface acoustic waves.

Local helioseismology has so far relied on semi-analytical methods to compute the spatial sensitivity of wave travel times to perturbations in the solar interior.

The first phase of our joint project has focused on the acoustic equation in axisymmetric domains with presence of flows. We have developed a dedicated target in our software Montjoie, which has been used by the German team as a direct numerical solver, to compute sensitivity kernels, and also in the context of an inverse problem in order to recover density, wave velocity, but also flows.

For now, the acoustic waves have been considered as a scalar data, although the measured data constitute a vectorial 3D velocity field. We now aim at modeling directly this vectorial field in order to take advantage of the full measured data.

Assignment

The Sun is constantly in motion because of the various physical phenomena happening inside it. These phenomena occur at very different time scales, and couple Navier Stokes fluid dynamics with Maxwell’s equations of electromagnetism. Acoustic waves are generated in the Sun for several reasons including turbulence, and can be considered as the perturbation around a background state that can be steady or very slow with respect to the acoustic time scale. These waves are therefore useful to probe the Sun’s interior at different times and detect the background dynamics.

Main activities

In this thesis, we wish to:

- propose a relevant and robust model for linearized acoustic waves around a “non quiet” Sun (in presence of flows and possibly sources). Possible linearized models include the Linearized Euler Equations (in Eulerian coordinates) and the Galbrun’s equations (in mixed Eulerian/Lagrangian coordinates) where the background state does not necessarily solve the homogeneous version of the same set of equations. Both lead to vectorial systems of convected wave equations,

- investigate their domain of validity in the context of helioseismology where the background medium is varying on several orders of magnitude in pressure and density,

- rigorously derive the source terms that appear in the model when the acoustic sources come from fluid turbulence and/or a magnetic field,

- construct artificial boundary conditions, in order to truncate the computational domain with the least possible impact on regional simulations,

- derive a Hybridizable Discontinuous Galerkin (HDG) method because the vectorial systems involve many unknowns and classical Discontinuous Galerkin (DG) methods are very heavy in terms of computational resources. In the team we now have a good experience with HDG for wave equations,
but we have never tried to develop this method in the presence of physical convection and therefore this is a new subject with high potential impact in terms of computational and memory gain. In the context of inversion, this issue is a real bottleneck for realistic applications.

**Keywords**: Sun, helioseismology, Hybridizable Discontinuous Galerkin, Galbrun

**References**:
- Computational helioseismology in the frequency domain: acoustic waves in axisymmetric solar models with flows, Laurent Gizon, Hélène Barucq, Marc Duruflé, Chris S. Hanson, Michael Leguèbe, Aaron C. Birch, Juliette Chabassier, Damien Fournier, Thorsten Hohage, Emanuele Papini, Astronomy&Astrophysics 600, A35 (2017)
- Hybridizable discontinuous Galerkin method for the two-dimensional frequency-domain elastic wave equations, Marie Bonnasse-Gahot Henri Calandra Julien Diaz Stéphane Lantern, Geophysical Journal International, ggx533, 2017

**Skills**
**Required Knowledge and background**: numerical analysis, PDE, scientific computing, C++

**Benefits package**
- Subsidised catering service
- Partially-reimbursed public transport

**Remuneration**
PhD grant of 3 years located in Pau, France
1982€ / month (before taxes) during the first 2 years, 2085€ / month (before taxes) during the third year.