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Investigation of the effects of Cowling approximation on adiabatic wave propagation in helioseismology

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1 Abstract

Helioseismology investigates the interior structures and the dynamics of the Sun from oscillations observed on its visible surface. Ignoring flow and rotation, time-harmonic adiabatic waves in a self-gravitating Sun in Eulerian-Lagrangian description are described by the Lagrangian displacement ξ and the gravitational potential perturbation δ_ϕ which satisfy Galbrun's equation [1] coupled with a Poisson equation. In most works, perturbation to gravitational potential δ_ϕ is neglected under Cowling's approximation [3]. However, this approximation is known to shift the eigenvalues of the forward operator for low-order harmonic modes [4]. Here, we study the effects of this approximation on numerical solutions and discuss its implication for the inverse problem. Removing Cowling's approximation allows us to accurately simulate waves for low-degree modes, and help us better characterize the deep interior of the Sun.

The investigation is carried out for a Sun with minimum activity, called quiet Sun, whose background coefficients are given by the radially symmetric standard solar model `Model S` in the interior, with a choice of extension beyond the surface to include the presence of atmosphere cf [5]. Radial symmetry is exploited to decouple the problem on each spherical harmonic mode ℓ to give a system of ordinary differential equations in radial variable. This extends previous work [1] which employed Cowling approximation. The modal system is resolved by using the Hybridizable Discontinuous Galerkin method (HDG). For purpose of validation, the equations are coupled with free-surface boundary condition which is adapted for low-frequency modes and is commonly employed in helioseismology cf. [6]. Since eigenvalues are poles of Green's tensor, the magnitude of the latter as a function of frequency peaks around an eigenvalue. As preliminary results, we compare the location where the Green's tensor peaks to the values of eigenvalues computed by the GYRE code [2], between which we find a good agreement.

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