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Dynamical role of Ekman pumping in rapidly rotating convection

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The exact nature of the mechanical boundary conditions (i.e. no-slip versus stress-free) is usually considered to be of secondary importance in the rapidly rotating parameter regime characterizing planetary cores. While they have considerable influence for the Ekman numbers achievable in today's global simulations, for planetary values both the viscous Ekman layers and the associated secondary flows are generally expected to become negligibly small. In fact, usually the main purpose of using stress-free boundary conditions in numerical dynamo simulations is to suppress unrealistically large friction and pumping effects.

In this study, we investigate the influence of the mechanical boundary conditions on core convection systematically. By restricting ourselves to the idealized case of rapidly rotating Rayleigh-Bénard convection, we are able to combine results from direct numerical simulations (DNS), laboratory experiments and asymptotic theory into a coherent picture. Contrary to the general expectation, we show that the dynamical effects of Ekman pumping increase with decreasing Ekman number over the investigated parameter range. While stress-free DNS results converge to the asymptotic predictions, both no-slip simulations and laboratory experiments consistently reveal increasingly large deviations from the existing asymptotic theory based on dynamically passive Ekman layers. The implications of these results for core dynamics are discussed briefly.