Connecting buoyancy dominated and magnetically dominated regimes in magnetoconvection

M. McCormack[*], A. Teimurazov[†], O. Shishkina[†] and M. Linkmann[*]

A long-standing question in thermal convection under the action of a magnetic field is how the dimensionless convective heat transport ($Nu-1$, where Nu is the Nusselt number) scales with the dimensionless thermal driving (Rayleigh number Ra) and the strength of the magnetic field (Hartmann number Ha), in different regimes. In magnetoconvection, where an electromagnetically conductive fluid is influenced by a vertical magnetic field, one may expect a scaling $Nu-1 \sim Ra^{\gamma}$ in the buoyancy dominated (BD) regime and $Nu-1 \sim (Ra/Ra_c)^{\xi}$ in the magnetically dominated (MD) regime, where $Ra_c = Ra_c(Ha)$ is the critical Ra for the onset of magnetoconvection.

In this talk, we extend the analytic scaling theory[1], which was originally developed for rotating Rayleigh–Bénard convection (RBC), to the case of RBC under the action of a vertical magnetic field. The theory connects the scaling exponents in the BD and MD regimes, i.e. derives a function $\xi = \xi(\gamma)$, done so through the matching of the thermal and kinetic boundary layer thicknesses at the transition between the two regimes. This provides a means to predict the scaling behaviour in strongly MD convection from only the measurement of the scaling exponent in the BD regime and vice versa. Further, we construct a scaling law that predicts the transition between these two regimes. The theory is supported by direct numerical simulations (DNS) of Lim et al.[2] ($Ha \leq 500$ for Prandtl number $Pr = 8$) and our own GOLDFISH DNS ($Ha = 500$, $Ra < 10^7$ for $Pr = 8$ and $10 \leq Ha \leq 2000$ for $Pr = 0.025$), see Fig. 1. The predicted scaling laws are also commensurate with experimental data of Cioni et al.[3]

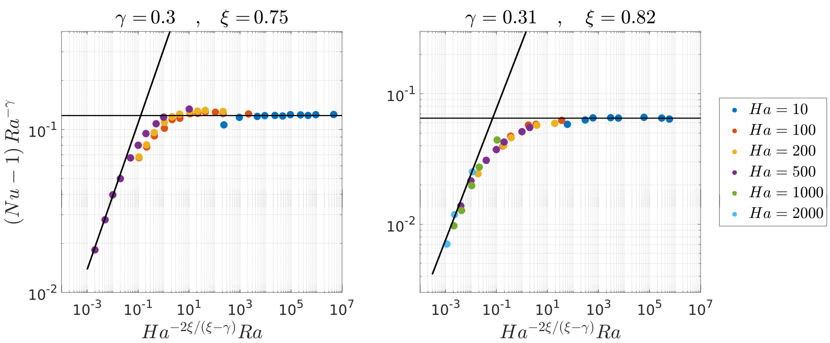

Figure 1: Collapse of the DNS data sets at $Pr = 8$ (left) and $Pr = 0.025$ (right) onto the curve governed by the predicted transitional scaling law $(Nu-1)Ra^{-\gamma} \sim [Ha^{-2\xi/(\xi-\gamma)}Ra]^{s}$, with the black lines denoting the scaling in the BD (measured) and MD (predicted) regimes.

[*]School of Mathematics and Maxwell Institute for Mathematical Sciences, University of Edinburgh, UK.

[†]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany.

[1]Ecke & Shishkina, *Annu. Rev. Fluid Mech.* **55**, 603–638 (2023), §3.3.

[2]Lim, et al., *J. Fluid Mech.* **870**, 519–542 (2019).

[3]Cioni et al., *Phys. Rev. E* **62**, 4 (2000).