Heat transport and flow morphology of geostrophic rotating Rayleigh-Bénard convection in the presence of boundary flow

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Using direct numerical simulations, we separately investigate the heat transport in the bulk and in the boundary flows in rotating Rayleigh-Bénard convection in cylindrical cells. In the bulk, we observe a steep scaling relationship between the Nusselt number (Nu) and the Rayleigh number (Ra), which is consistent with the results from simulations using periodic boundary conditions. For the boundary flow, we observe a power-law $Nu_{BF} \sim (Ra/Ra_w)^1$, as shown in Fig. 1(a). Here Nu_{BF} is the local Nusselt number of the boundary flow and Ra_w is the onset Rayleigh number of wall-mode. We further develop a model using the boundary layer marginal stability theory to explain this power-law. A striking finding of our study is the observation of a sharp transition in flow state, manifested by a sudden drop in Nu_{BF} with a corresponding collapse of the boundary flow coherency. After the transition, the boundary flow breaks into vortices, as illustrated by Figs. 1(b) and (c). Such transition gives rise to a reduction in flow coherency and heat transport efficiency. As the physical properties of the vortices should not depend on the aspect ratio, Nu_{BF} for all aspect ratios collapse together after the transition. We further develop a method that enables us to separate the contributions from the bulk and boundary flows in the global Nusselt number using only the global Nu and it does not require the absence of the centrifugal force. This work is supported by the National Natural Science Foundation of China (Grant No. 12072144); and the Research Grants Council of HKSAR (Grant No. CUHK14301115 and CUHK14302317).

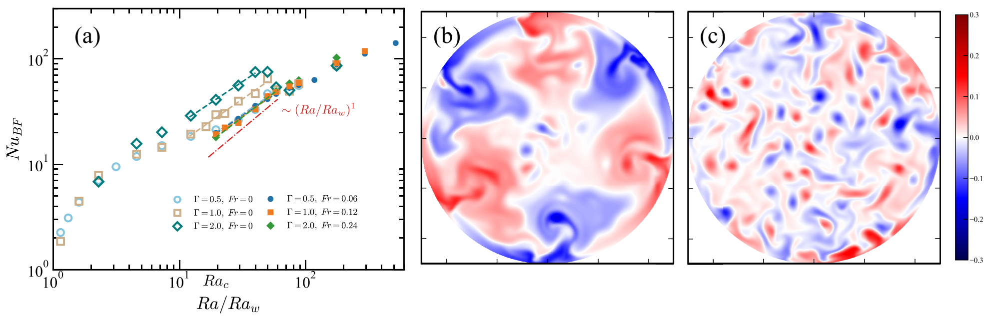

Figure 1: (a) Nu_{BF} as a function of Ra/Ra_w. Panels (b) and (c) respectively correspond to the temperature distribution at the mid-height for (b) the coherent boundary flow state and (c) the vortical boundary flow state.

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