Comment on "Effect of Boundary Layers Asymmetry on Heat Transfer Efficiency in Turbulent Rayleigh-Bénard Convection at Very High Rayleigh Numbers"

In turbulent Rayleigh-Bénard convection (a fluid between two parallel horizontal plates and heated from below) a transition was predicted to occur [1,2] with increasing Rayleigh number Ra from a "classical" state with laminar boundary layers (BLs) to an "ultimate" state with turbulent BLs. Recently, this transition was found in measurements of the Nusselt number Nu and Reynolds number Re as a function of Ra [3–6].

The central claim of a recent Letter by Urban *et al.* [7] was that measurements of Nu can erroneously indicate the existence of an ultimate-state transition when the fluid properties used to compute Nu and Ra are evaluated using the mean temperature $T_m = (T_b + T_t)/2$ of the bottom (T_b) and top (T_t) of the sample rather than the temperature T_c at the sample center. It is well known that for a Boussinesq sample $T_c = T_m$; thus, the large differences between T_c and T_m observed by Urban *et al.* show that their samples deviated strongly from the Boussinesq approximation. Here we show that the misleading phenomenon observed by Urban *et al.* is an artifact caused by the particular parameter choices of their experiment which led to the strong non-Boussinesq effects. Thus, their results are irrelevant to the predicted ultimate-state transition [1,2] which was for Boussinesq systems. Their conclusions have no bearing on previous experiments that reported the ultimate-state transition [3–6] and, we expect, indeed on most other experiments in the field, which were done under much more nearly Boussinesq conditions.

The claim by Urban *et al.* that the Ra value Ra^* predicted half a century ago by Kraichnan [1] for the ultimate-state transition has "not yet (been) achieved in any laboratory" misleads the uninformed reader to believe that indeed the transition has not yet been found. The authors neglected to mention that a more realistic value of $\mathrm{Ra}^* \simeq 10^{14}$ [8] based on a modern analysis has been within reach of current experiments, and that the transition indeed was found in recent experiments near $\mathrm{Ra}^* \simeq 10^{14}$ and studied in great detail both for aspect ratio $\Gamma = 0.50$ [3,4,6] and (to a lesser extent) for $\Gamma = 1.00$ [5]. The statement by Urban *et al.* that "Our results… suggest strongly that experimental investigation of this issue… (such as Refs. [8, 9, 15]) ought to be interpreted with extreme care" (their Ref. [15] is to our Letter [3]) is unjustified. Although we agree that all experimental results should always be viewed with care, we show that the particular concerns which are the central aspect of the Letter by Urban *et al.* are relevant only to their own investigation of a highly non-Boussinesq system and not to the other investigations in the field which utilized much more nearly Boussinesq samples.

As seen in Fig. 1, for the near-Boussinesq system of [5] the differences between the results for Ra and Nu that prevail when either T_c or T_m is used to evaluate the fluid properties are extremely small (see also Sec. 2 of [5]). The differences in the reduced Nu are only 0.3% or less. This is utterly negligible in the context of the investigation of Urban *et al.* which yielded differences as large as 40%. In part, this is so because for the measurements of [5,6] $|\Phi| \equiv |(T_c - T_m)|/\Delta T \lesssim 0.03$, while for [7] $|\Phi|$ becomes as large as 0.12. Further, close to the critical point of a gas, where Urban *et al.* made their measurements, the fluid properties vary much more rapidly with the temperature than they do well away from the critical point where the work of [3–6] was done.

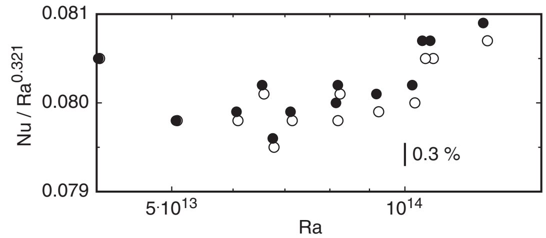

FIG. 1. The reduced Nusselt number $\mathrm{Nu}/\mathrm{Ra}^{0.321}$ as a function of the Rayleigh number Ra for some of the data from [5] ($\Gamma = 1.00$; results for $\Gamma = 0.50$ [4] are similar). Solid (open) circles: fluid properties evaluated at T_m (T_c).

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[1] R. H. Kraichnan, Phys. Fluids **5**, 1374 (1962).
[2] S. Grossmann and D. Lohse, Phys. Fluids **23**, 045108 (2011).
[3] X. He, D. Funfschilling, H. Nobach, E. Bodenschatz, and G. Ahlers, Phys. Rev. Lett. **108**, 024502 (2012).
[4] G. Ahlers, X. He, D. Funfschilling, and E. Bodenschatz, New J. Phys. **14**, 103012 (2012).
[5] X. He, D. Funfschilling, E. Bodenschatz, and G. Ahlers, New J. Phys. **14**, 063030 (2012).
[6] G. Ahlers, E. Bodenschatz, D. Funfschilling, S. Grossmann, X. He, D. Lohse, R. J. A. M. Stevens, and R. Verzicco, Phys. Rev. Lett. **109**, 114501 (2012).
[7] P. Urban, P. Hanzelka, T. Kralik, V. Musilova, A. Srnka, and L. Skrbek, Phys. Rev. Lett. **109**, 154301 (2012).
[8] S. Grossmann and D. Lohse, Phys. Rev. E **66**, 016305 (2002).

