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ADDENDUM • OPEN ACCESS

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Addendum

Transitions in heat transport by turbulent convection at Rayleigh numbers up to 10^{15}

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Abstract. In the original paper by Ahlers *et al* (2009 *New J. Phys.* **11** 123001) a transition was reported at a Rayleigh number $Ra = Ra^* \simeq 4 \times 10^{13}$. For $Ra > Ra^*$, the Nusselt number Nu rose less rapidly with increasing Ra than it did below Ra^*. In a note added in proof the authors reported the subsequent discovery of a coexisting additional 'upper branch' where Nu increased more rapidly with Ra. This addendum reports more extensive measurements of $Nu(Ra)$ on the upper branch, which yield $Nu \propto Ra^{0.36}$.

In our original paper [1], we presented results for heat transport (in the form of the Nusselt number Nu) as a function of the applied temperature difference (in the form of the Rayleigh number Ra) over the range $10^{11} \lesssim Ra \lesssim 10^{15}$. As described in that paper, those measurements were made with a sample located in a large pressure vessel known as the 'Uboot of Göttingen'. The pressure vessel, and the sample within it, were filled with sulfur hexafluoride (SF_6) to various pressures up to 19 bars in order to achieve various ranges of Ra.

The measurements reported by us before showed that $Nu \propto Ra^{0.308}$ for $Ra < Ra^* \simeq 4 \times 10^{13}$, and that at Ra^* there is a transition to a new state with $Nu \propto Ra^{0.25}$. A further transition was reported for Ra near 2×10^{14} to yet another state with $Nu \propto Ra^{0.17}$. The experiments leading to these results were made at mean sample temperatures $T_m \gtrsim 25\,^\circ C$. During those runs, we believe that we had Uboot temperatures $T_U \lesssim 25\,^\circ C$, although T_U was not actually measured.

In a note added in proof to our paper we reported that yet another convecting state exists near $Ra \simeq 10^{15}$ with substantially larger Nu values than those for the other states. The larger-Nu state was achieved by operating the sample at a temperature $T_m \simeq 21\,^\circ C < T_U \simeq 25\,^\circ C$. The importance of $T_m - T_U$ suggests that a small current of gas could flow through gaps of widths that were approximately equal to 1 mm between the top and the bottom plate and the side wall from the sample into the Uboot and vice versa (the gaps had been left open intentionally to

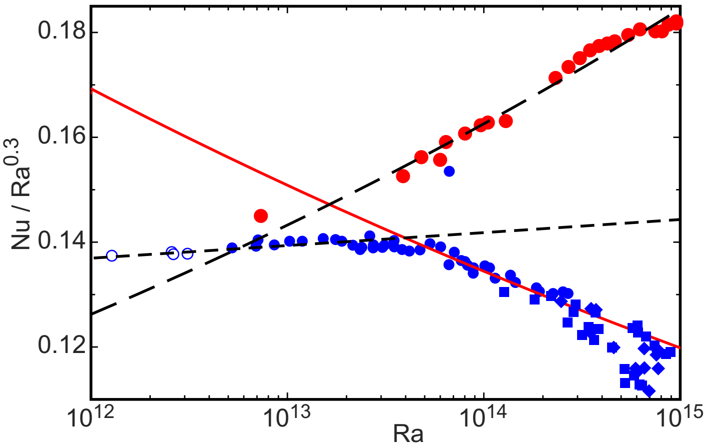

Figure 1. The reduced Nusselt number $Nu/Ra^{0.3}$ as a function of the Rayleigh number Ra on a logarithmic scale. The small blue symbols are the data reported in figure 7 of the original article. They were obtained with $T_m > T_U \lesssim 25\,°C$. The large solid red circles are new data obtained with $T_m \simeq 21\,°C < T_U$. The long dashed line corresponds to $Nu \propto Ra^{0.36}$. The other two lines are as given in figure 7 of the original paper.

permit filling the sample with gas). This current, if it existed, is assumed to have been driven by the small difference in density at the same pressure but at different T_m and T_U. The sensitivity to $T_m - T_U$ suggests further that the heat transport in this system and at these Ra is extremely sensitive to details of the external conditions. In figure 1, we show additional data obtained with $T_m \simeq 21\,°C$ as large solid red circles. The previously reported data are shown as smaller blue symbols. The new data can be fit well by $Nu \propto Ra^{0.36}$ (solid red line). The new data were reported first in January 2010 in a lecture at the Euromech Colloquium #520 in Les Houches [2].

References

[1] Ahlers G, Funfschilling D and Bodenschatz E 2009 *New J. Phys.* **11** 123001
[2] http://www.hirac4.cnrs.fr/HIRAC4_Workshop_on_High_Ra_convection.html