Towards controlling the blackbody radiation shift in a strontium lattice clock at the 10^{-19} level

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Blackbody radiation (BBR) causes the largest frequency shift with respect to the (5s5p) $^3P_0$ – ($5s^2$) $^1S_0$ clock transition of strontium lattice clocks operated near room temperature. Characterising this shift to better than about 1×10^{-18} of the transition frequency is not possible at present due to the knowledge of the atomic response and requires reliably determining the effective temperature of the BBR field to better than 10 mK, which is highly challenging. Operating a clock in a cryogenic environment reduces the BBR field and relaxes the requirements on temperature determination significantly, but usually requires careful consideration of residual influx of external, room-temperature BBR.

We report on the current status of the PTB-Sr3 strontium lattice clock for room-temperature operation and of characterising and controlling the BBR-induced frequency shifts during cryogenic operation ($T \approx 80$ K). The apparatus has been designed to control the clock frequency shift due to BBR at the level of 2×10^{-19} or below. We discuss the actively temperature-controlled cryogenic environment, in which strontium atoms are both prepared and interrogated, the influence of residual BBR entering through free-space access ports and means to mitigate it, as well as the influence of residual BBR entering through glass viewports and how absorption in the medium affects the spectral distribution of the BBR field. We also present examples of clock operation below room temperature (Fig. 1) and report on the provisioning of passively cooled shutters to block free-space access ports, which will be installed later in 2024.

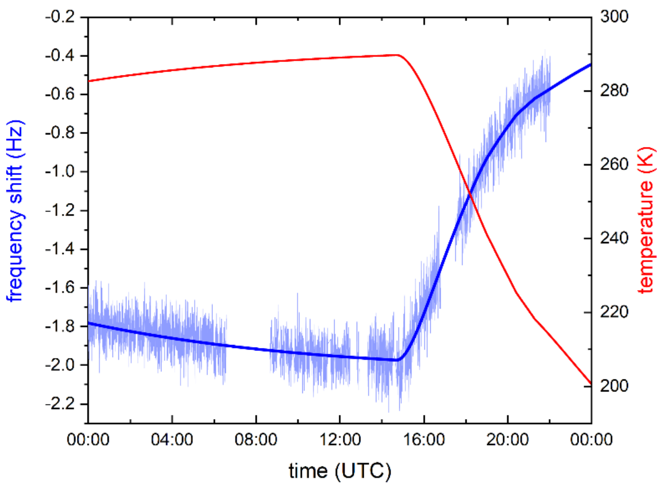

Fig. 1: Measured (light blue) and expected (dark blue) frequency shift due to BBR when cooling down the clock apparatus (red curve: effective temperature) during operation, over a period of about 24 hours. The initial rise in temperature results from reheating following a previous period of cryogenic operation.

Finally, we discuss lessons learned from room-temperature operation regarding other systematic effects, such as the DC-Stark shift caused by residual electric fields, and outline the next steps to control these effects at the 10^{-19} level, including planned upgrades to the apparatus.

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