Ca^+ Optical clocks with Systematic Uncertainties at the 10^{-18} level

Yao Huang[1], Hua Guan[1], Kelin Gao[1]

1. Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences

email: yaohuang@apm.ac.cn

Here our progress on the Ca^+ ion optical clocks for the last few years will be reported, including both the laboratory clocks and the transportable clock.

First of all, the clock stability is greatly improved, with long term stability reaches the 10^{-18} level [1,2]; recently with a low 10^{-16} level stability clock laser, the clock stability has been improved to ~ $1 \times 10^{-15}/\sqrt{\tau}$, about another factor of 2 improvement and about an order of magnitude smaller than that in 2016 [3]. Secondly, a cryogenic Ca^+ clock at the liquid nitrogen environment is built, with the blackbody radiation (BBR) shift uncertainty greatly suppressed, and improvements made with other systematic uncertainties, the overall systematic uncertainty of the clock is evaluated as 3.0×10^{-18} [4]. Thirdly, the Ca^+ clock at room temperature is also improved. The systematic uncertainty of the room temperature clock was at the 10^{-17} level [3], limited by the BBR shift uncertainty. To lower the BBR shift uncertainty, the precise measurement of the differential scalar polarizability through of the clock transition is taken [5], and the active liquid-cooling scheme is adopted, combined with the precise temperature measurement with 13 temperature sensors. The BBR field temperature uncertainty is then evaluated as 0.4 K, corresponding to a BBR shift uncertainty of 4.6×10^{-18}, then the overall systematic uncertainty of the room temperature clock is evaluated as 4.9×10^{-18}. Clock frequency comparison between the room temperature clock and the cryogenic clock is taken for testing the systematic shift uncertainty evaluations, and the two clocks show an agreement at the 10^{-18} level after the systematic shift corrections: With the systematic shift corrections, the frequency difference between the two clocks is measured as $1.8(7.5) \times 10^{-18}$, the overall uncertainty includes a statistic uncertainty of 4.9×10^{-18} and a systematic uncertainty of 5.7×10^{-18}.

Besides the laboratory clocks mentioned above, a transportable Ca^+ ion clock is also built, with an uncertainty of 1.3×10^{-17} and an uptime rate of > 75% [6]. With the comparison between the transportable clock and the laboratory clock, a demonstration of geopotential measurement with clocks has been made. The clock is then transported for > 1200 km to another institute, the absolute frequency measurement is made there with an uncertainty of 5.6×10^{-16} [6], about 5 times smaller than our previous result [3]. Recently, a new round, 35-day-long absolute frequency measurement is taken, with improvements made such as the increase of the uptime rate to 91.3 %, the reduced statistical uncertainty of the comparison between the optical clock and hydrogen maser, and the use of longer measurement times to reduce the uncertainty of the frequency traceability link. The uncertainty of the absolute frequency measurement is further reduced to 3.2×10^{-16}, which is another factor of 1.7 improvement.

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