

# Development of the Cesium Fountain Frequency Standard, NMIJ-F2

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We have made much progress on NMIJ-F2, which is our second cesium fountain frequency standard aiming an uncertainty of  $< 1 \times 10^{-15}$ . To improve the frequency stability, a cryogenic sapphire oscillator (CSO) using a pulse-tube cryocooler [1] was applied to NMIJ-F2 as a local oscillator, and optical pumping to the Zeeman sublevel  $m_F = 0$  was performed [2]. Then, the homogeneous magnetic field in the interrogation region was obtained with magnetic shielding and a solenoid coil. Currently, the estimation of a collisional shift is ongoing. In this presentation, we describe the current status of the development of NMIJ-F2.

Figure 1 shows the Allan deviations of the frequency of NMIJ-F2 against the free-run CSO. Here, the red dots indicate the cases where the optical pumping was performed a few milliseconds after the launching while the blue dots show the case where the optical pumping was not performed. The green broken line indicates the frequency stability of the CSO. It is found that the frequency stability of NMIJ-F2 was improved from  $2.2 \times 10^{-13} \tau^{-1/2}$  ( $\tau$ : averaging time) to  $8.4 \times 10^{-14} \tau^{-1/2}$  by the optical pumping. It should be noted that a cryocooled CSO had not been applied to an atomic fountain until this experiment, and that vapor-loaded optical molasses in (001) configuration, with which it is more complicated to obtain high atomic number than a magneto-optical trap and beam-loaded optical molasses, was employed.

Figure 2 shows the vertical magnetic field in the interrogation region measured by obtaining Ramsey fringes using atoms in  $m_F = +1$  for various launching heights. It is found that the magnetic field was homogeneous within a level of 0.8 nT over the interrogation region.

[1] J. G. Hartnett et al., Appl. Phys. Lett. **100**, 183501 (2012). [2] K. Szymaniec et al., Appl. Phys. B, **111**, 527 (2013).

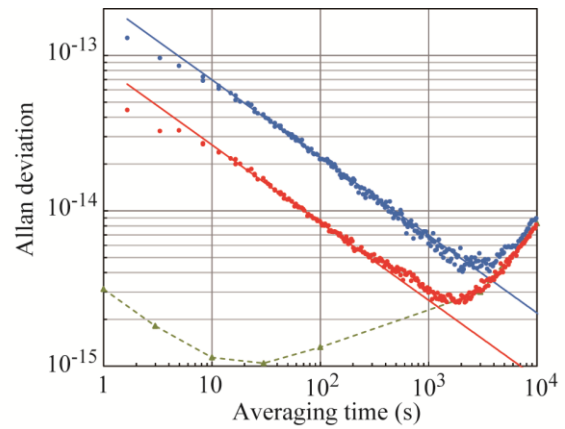


Fig. 1. Allan deviations of the frequency of NMIJ-F2 against the CSO.

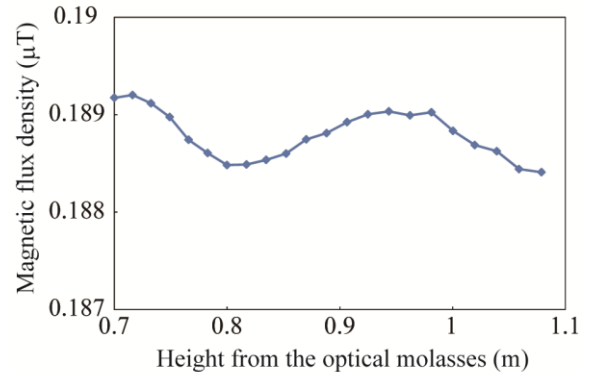


Fig. 2. The magnetic field in the interrogation region.