

Introduction

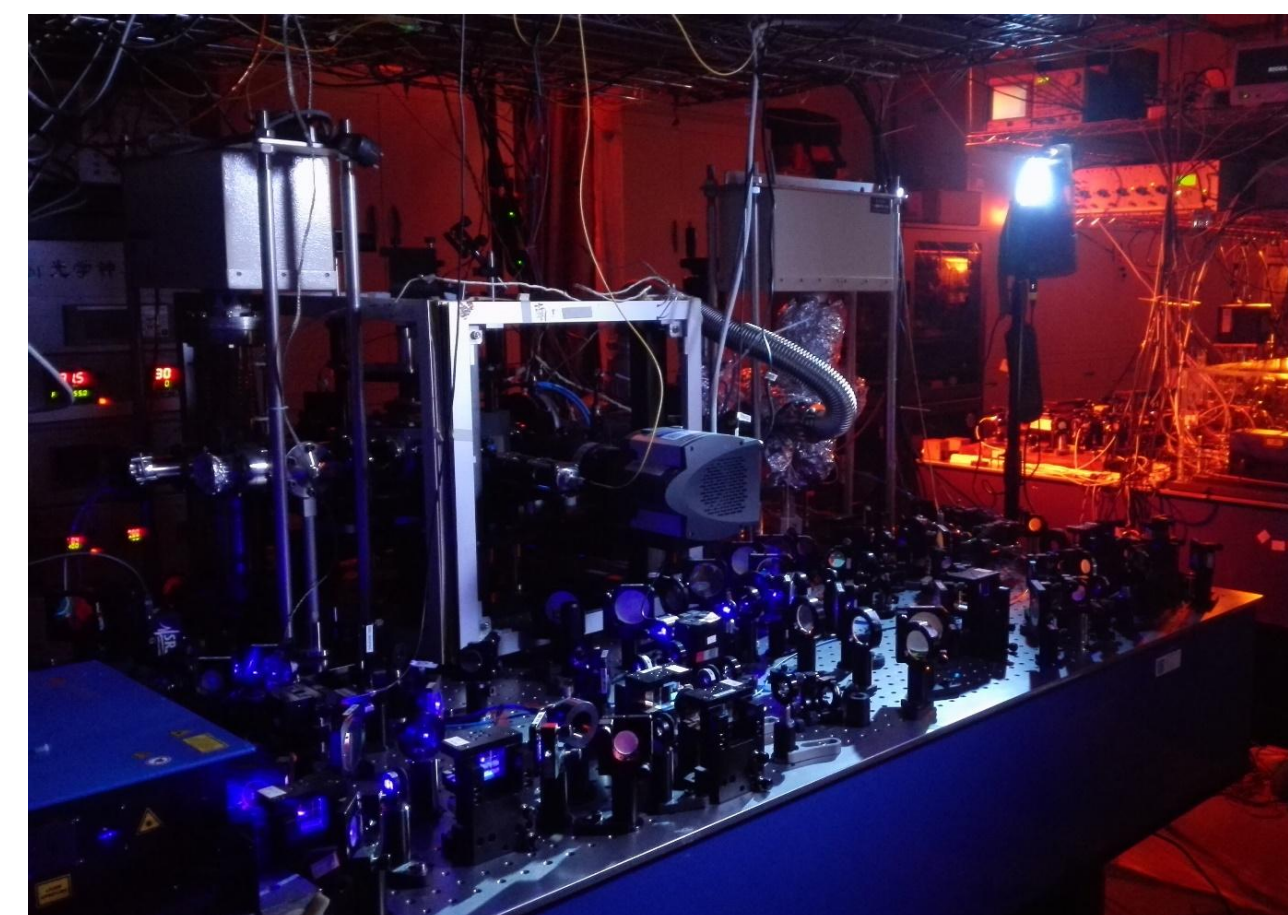
NIM has been conducting research on primary frequency standards for decades, from Cs beam clocks to atomic fountain clocks. The NIM5 Cs fountain clock has been contributing to the calibration of TAI since 2014. A new fountain clock NIM6 has been developed. With a three-dimensional magneto-optical trap (3D MOT) loading optical molasses to obtain more cold atoms rapidly and efficiently with a tunable, uniform density distribution, and a heat pipe surrounding the flight tube to maintain a consistent and stable temperature within the interrogation region, NIM6 achieved a short-term instability of $1.0 \times 10^{-13} \tau^{-1/2}$ at high atomic density, and a typical overall fractional type B uncertainty estimated to be 2.3×10^{-16} .

Two Sr optical lattice clocks have been developed. The type B uncertainty of NIM-Sr1 reached 2.9×10^{-17} , and its absolute frequency was measured against the primary and secondary frequency standards (PSFS) ensemble in Circular T bulletin through UTC(NIM) with an uncertainty of 3.1×10^{-16} . NIM-Sr2 lattice clock was built with a better black body radiation (BBR) environment control and the total uncertainty reached 6.5×10^{-18} . Ultra-stable lasers based on 30 cm reference cavities have been built to improve the stability of the Sr clocks, and a short term instability of 2.0×10^{-16} has been achieved. The two Sr clocks were located on two campuses about 40 km apart with fiber links to compare their frequencies, and a fractional frequency difference of $1.9(3.2) \times 10^{-17}$ was obtained, which showed good agreement.

A new Yb⁺ optical clock is under developing. The closed-loop operation of the E3 transition has been achieved with an instability of $1.7 \times 10^{-15} \tau^{-1/2}$.

Sr optical lattice clocks

Since 2006



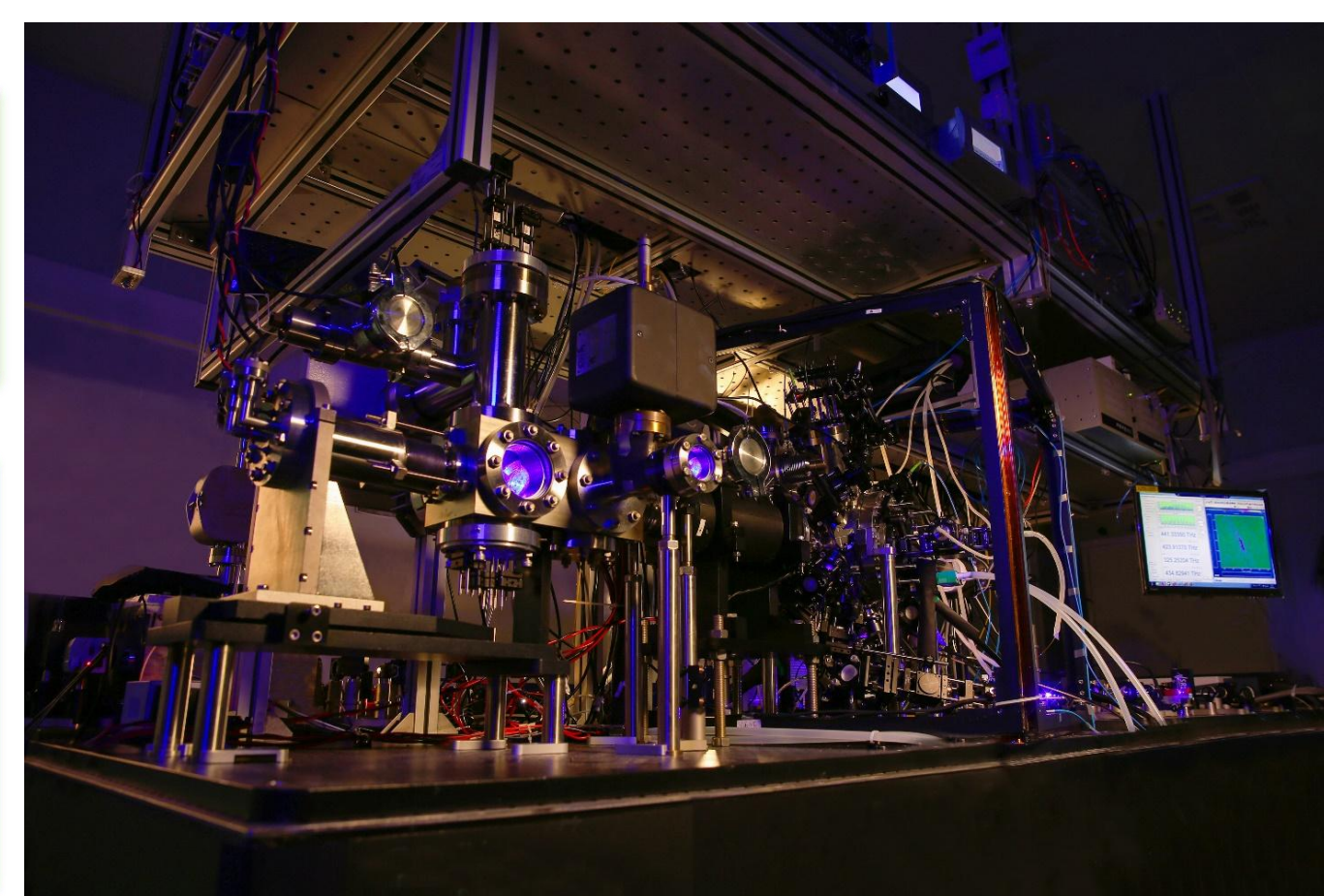
NIM-Sr1

2015
NIM-Sr1
 $u_B: 2.3 \times 10^{-16}$
Absolute frequency: 3.4×10^{-15}

2021
NIM-Sr1
 $u_B: 2.9 \times 10^{-17}$
Absolute frequency: 3.1×10^{-16}

2024
NIM-Sr2
 $u_B: 6.5 \times 10^{-18}$

2024
NIM-Sr1 vs NIM-Sr2
Fractional frequency difference:
 $1.9(3.2) \times 10^{-17}$



NIM-Sr2

Cs beam clock

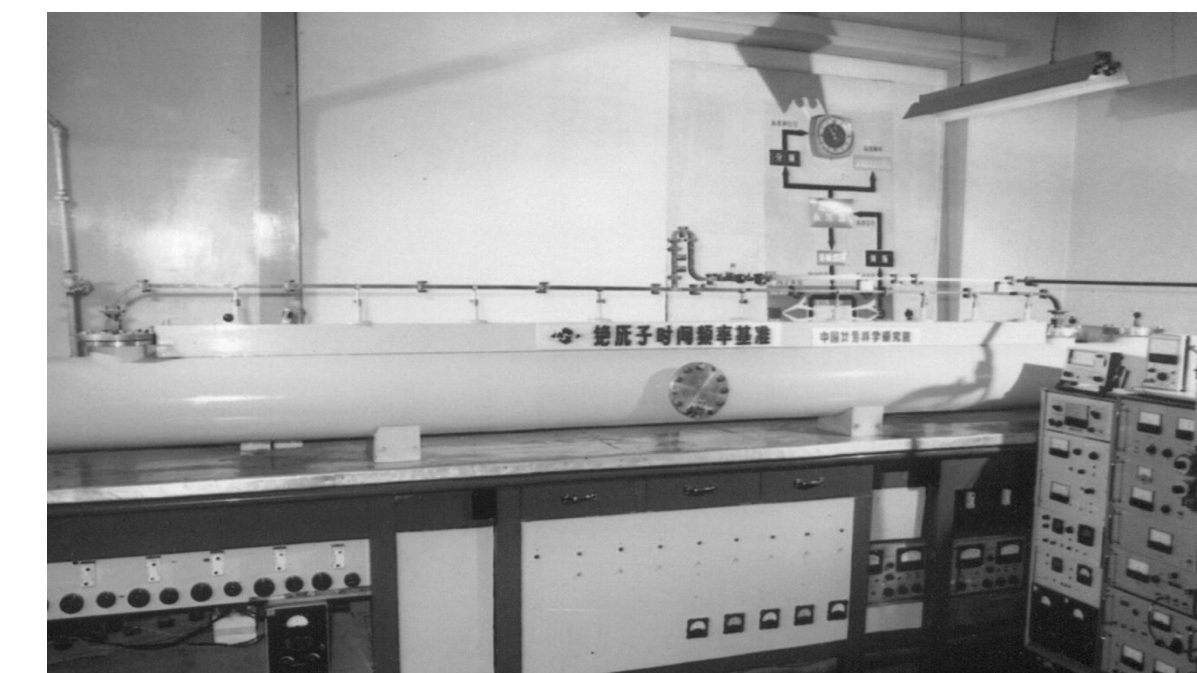
Since 1965



NIM1

1977
NIM1
 $u_B: 1 \times 10^{-11}$

1980
NIM2
 $u_B: 8 \times 10^{-13}$



NIM2

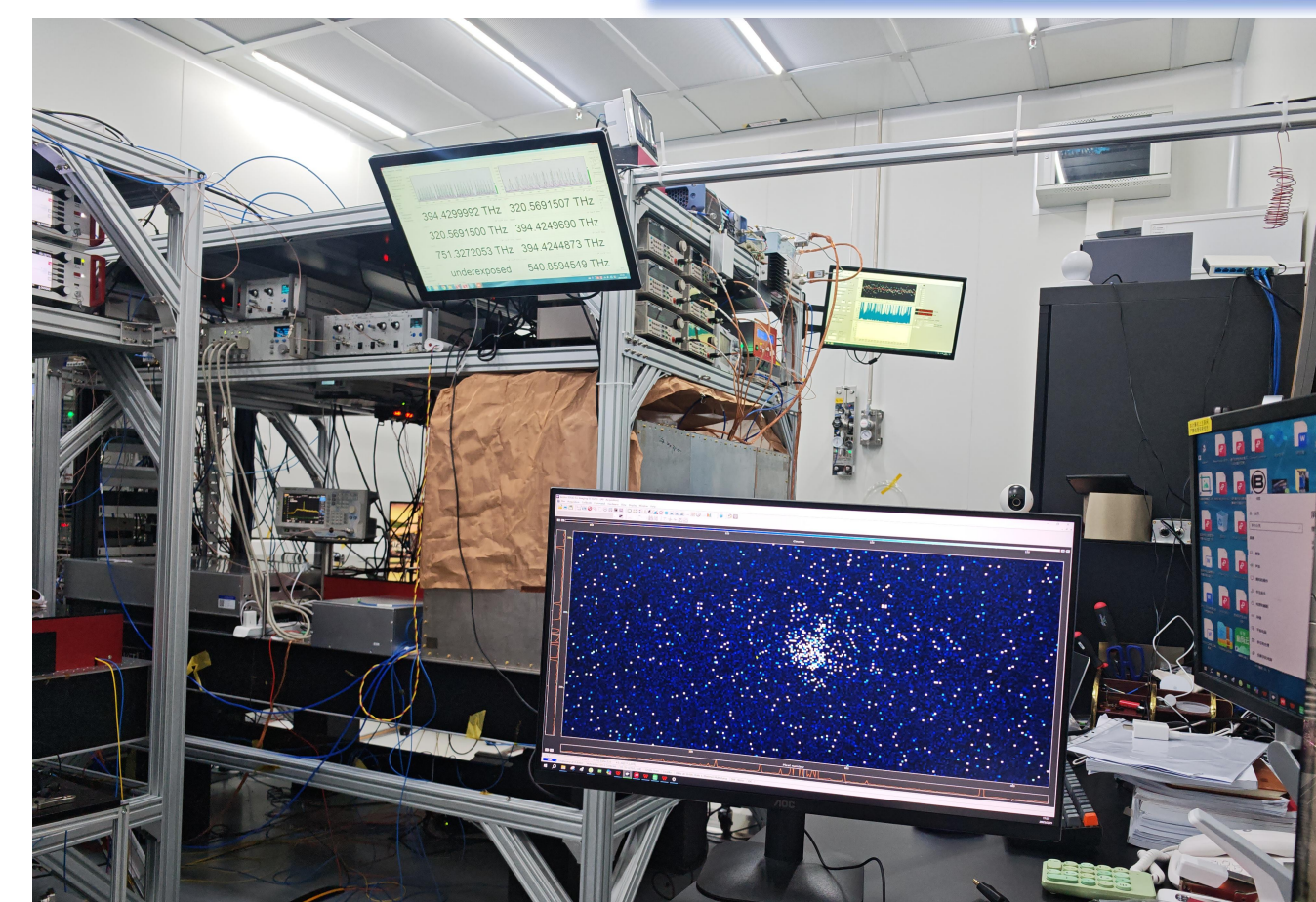


NIM3

1986
NIM3
 $u_B: 3 \times 10^{-13}$

Yb⁺ optical clock

Since 2021



NIM-Yb1

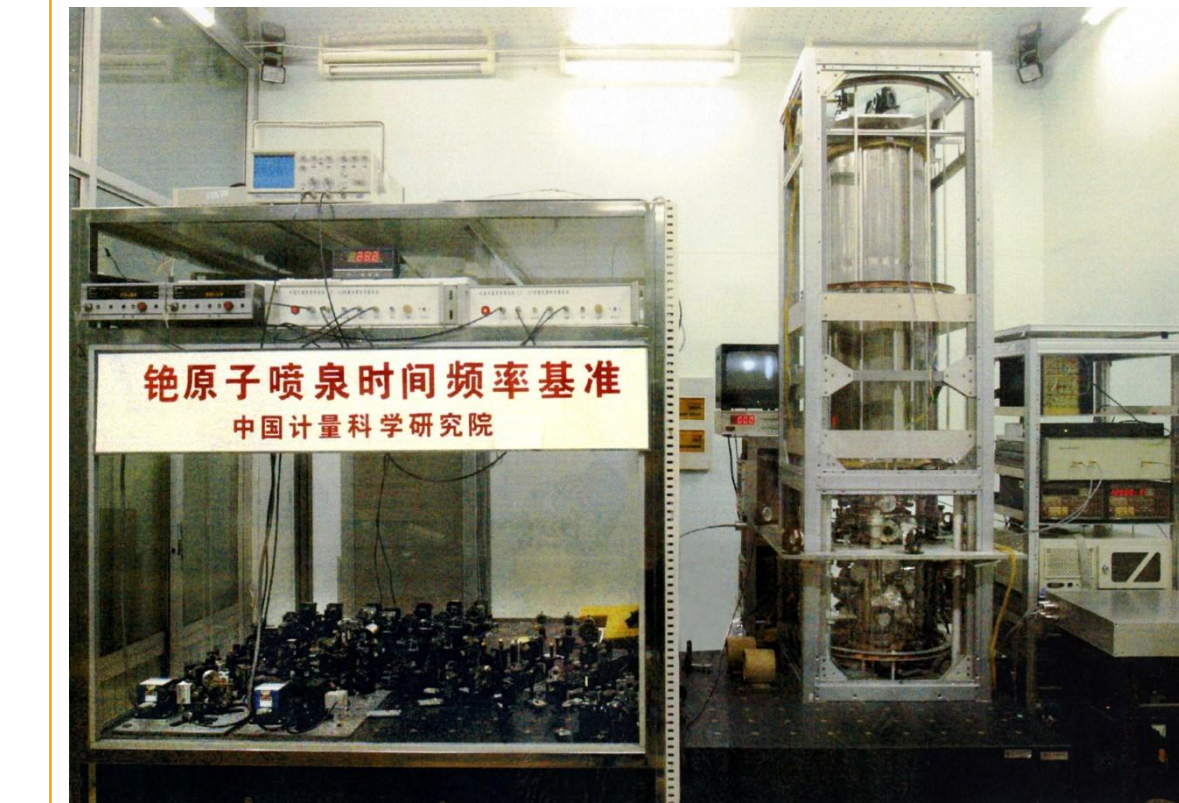
2025
NIM-Yb1
Instability:
 $1.7 \times 10^{-15} \tau^{-1/2}$

Outlook

NIM6 and NIM-Sr1 will contribute to the calibration of TAI together with NIM5 soon. The subsequent goal of the Sr and Yb⁺ optical clock research is to achieve systematic uncertainty below 2×10^{-18} . NIM will conduct ratio measurements between optical clocks and strive to help the optical clock research institutes in China to contribute to the redefinition of the SI second.

Cs/Rb fountain clock

Since 1997



NIM4

2003
NIM4
 $u_B: 8.5 \times 10^{-15}$



NIM5

2010
NIM5
 $u_B: 2 \times 10^{-15}$

2022 NIM-RbF2
Instability: $4.1 \times 10^{-16} @ 1d$



NIM-RbF2

2024
NIM5
 $u_B: 6.8 \times 10^{-16}$

2024
NIM6
 $u_B: 2.3 \times 10^{-16}$



NIM6

Conclusion

NIM has conducted decades-long research on primary and secondary frequency standards, not only establishing China's capability to reproduce the definition of the SI second, but also contributing to the calibration of TAI, thereby making noteworthy contributions to the international time and frequency community. The redefinition of the SI seconds has emerged as the paramount mission for the global metrology community in the near future, and NIM is willing to take this opportunity to make more contributions.

References

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- [2] W. Chen, F. Fang, K. Liu, F. Zheng, S. Dai, Y. Zuo and T. Li, Development of Rb fountain clock for time keeping, Front. Phys. 10, 956452 (2022).
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