Frequency evaluation of Maser 1401104 by IT-Yb1 for the period MJD 59744 to 59759

During the period MJD 59744 – 59759 (14 June 2022–29 June 2022) INRIM evaluated the frequency of the hydrogen maser IT-HM4 (BIPM code 1401104) using the Yb optical lattice frequency standard IT-Yb1 and an optical frequency comb. The evaluation is based on the CCTF2021 recommended frequency for ^{171}Yb as a secondary representation of the second, $f(^{171}\mathrm{Yb}) = 518\,295\,836\,590\,863.63\,\mathrm{Hz}$ with a relative standard uncertainty of $u_{\mathrm{Srep}} = 1.9 \times 10^{-16}$ [1, 2]. The results of the evaluation are summarized in Tab. 1. Details of IT-Yb1 operation and uncertainty budget are given in Refs. [3, 4] and summarized below.

1 Frequency measurement

The clock laser of IT-Yb1 is stabilized on an ultrastable cavity and probes ^{171}Yb atoms trapped in an optical lattice at the magic frequency. A digital control loop acting on an acousto-optic modulator keeps the clock laser frequency in resonance with the atoms. The cavity-stabilized laser is sent to a fibre frequency comb referenced to IT-HM4. The frequency ratio between the ^{171}Yb transition and IT-HM4 is calculated from the comb measurements and the corrections used for steering the acousto-optic modulator.

Table 1: Final evaluation using IT-Yb1.

Period of estimation	y(HM1401104 /ITYb1) $/10^{-16}$	u_{A} $/10^{-16}$	u_{B} $/10^{-16}$	$u_{\mathrm{A/lab}}$ $/10^{-16}$	$u_{\mathrm{B/lab}}$ $/10^{-16}$	u_{Srep} $/10^{-16}$	Uptime
59744–59759	31.0	0.04	0.23	2.2	0.2	1.9	23.6%

Table 2: Uncertainty budget for IT-Yb1 for the reported period.

Effect	Rel. Shift/10^{-17}	Rel. Unc./10^{-17}
Density shift	-0.2	0.4
Lattice shift	0.4	1.1
Zeeman shift	-3.14	0.03
Blackbody radiation shift (room)	-234.3	1.4
Blackbody radiation shift (oven)	-1.4	0.7
Static Stark shift	-1.5	0.9
Probe light shift	0.04	0.03
Background gas shift	-0.5	0.2
Servo error	0.0	0.3
Other shifts	0.0	0.1
Grav. redshift (static)	2599.5	0.3
Grav. redshift (tides)	0.0	0.2
Total	2358.9	2.3

Table 3: Uncertainty budget for the link between IT-Yb1 and IT-HM4 for the reported period.

Effect	Uncertainty/10^{-16}
Comb statistic	0.1
Extrapolation (dead time)	2.0
Extrapolation (drift)	1.0
Total $u_{\mathrm{A/lab}}$	2.2
Optical/microwave comp. (type B)	0.2
Total $u_{\mathrm{B/lab}}$	0.2

2 IT-Yb1 evaluation

The uncertainty u_A is the statistical contribution from the instability of IT-Yb1. The uncertainty u_B is the systematic uncertainty of IT-Yb1 [4]. The systematic frequency shift and uncertainty budget of IT-Yb1 for the reported period are given in Tab. 2. IT-Yb1 now operates with a vertical optical lattice and the lattice light shift calculations have been updated following Ref. [5]. The table includes the gravitational redshift relative to the conventional potential $W_0 = 62\,636\,856.0\,\mathrm{m}^2\mathrm{s}^{-2}$ [4].

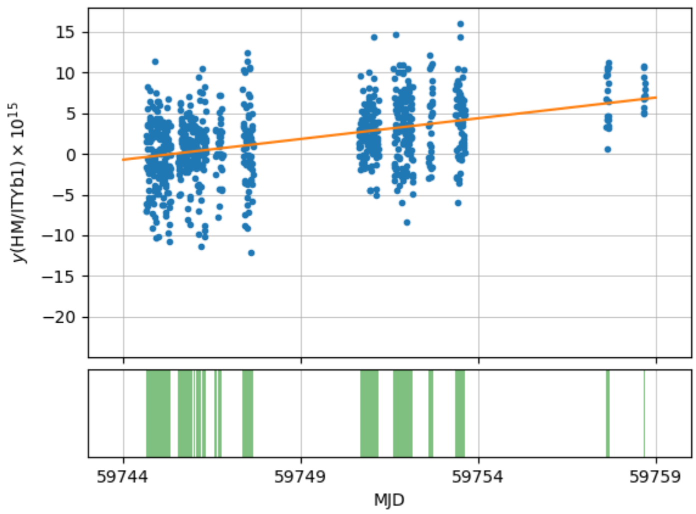

Figure 1: Fractional frequency deviation y(HM1401104/ITYb1) measured in the period MJD 59744 - 59759. Green shaded regions in the bottom plot represent the uptime of IT-Yb1.

3 Link evaluation

The uncertainty $u_{\mathrm{l/lab}}$ is due to the link between IT-Yb1 and IT-HM4, including the optical to microwave comparison at the comb. Table 3 summarizes the contributions to this uncertainty.

The comparison uncertainty between optical and microwave signals at the comb has been evaluated from comparison with a second optical frequency comb.

IT-Yb1 and the comb were operated for 305 726 s (uptime 23.6% of the evaluation period). The data collected and the distribution of the uptimes of IT-Yb1 are shown in Fig. 1. Data collected in June 2022 has been separated in two periods following a maser jump at MJD 59737. Extrapolation using the maser as a flywheel is needed given the intermittent operation of IT-Yb1. Its evaluation is separated in an uncertainty from dead times and a correction for the maser drift. The maser drift of $5.1(4) \times 10^{-16}$ /d has been calculated from IT-Yb1 data collected in the period. The contribution from dead times has been evaluated following the approach in Ref. [6]. For this measurement we considered the IT-HM4 noise to be a power-law model described by the Allan deviation: white phase noise $3 \times 10^{-13}(\tau/\mathrm{s})^{-1}$; white frequency noise $4 \times 10^{-14}(\tau/\mathrm{s})^{-1/2}$; flicker frequency noise 3×10^{-16}; random walk frequency noise $2 \times 10^{-19}(\tau/\mathrm{s})^{1/2}$.

Contributors

Marco Pizzocaro, Stefano Condio, Irene Goti, Cecilia Clivati, Matias Risaro, Filippo Levi, Davide Calonico

References

[1] Consultative Committee for Time and Frequency (CCTF), "Recommendation CCTF PSFS 2: Updates to the CIPM list of standard frequencies," 2021. Online: https://www.bipm.org/en/committees/cc/cctf/22-_2-2021

[2] Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the definition of the second. Online: https://www.bipm.org/en/publications/mises-en-pratique/standard-frequencies.html

[3] M. Pizzocaro, P. Thoumany, B. Rauf, F. Bregolin, G. Milani, C. Clivati, G. A. Costanzo, F. Levi, and D. Calonico, "Absolute frequency measurement of the $^1S_0$ – $^3P_0$ transition of ^{171}Yb," *Metrologia*, vol. 54, no. 1, pp. 102–112, 2017. Online: http://stacks.iop.org/0026-1394/54/i=1/a=102

[4] M. Pizzocaro, F. Bregolin, P. Barbieri, B. Rauf, F. Levi, and D. Calonico, "Absolute frequency measurement of the $^1S_0$ – $^3P_0$ transition of ^{171}Yb with a link to international atomic time," *Metrologia*, vol. 57, no. 3, p. 035007, may 2020. Online: https://doi.org/10.1088%2F1681-7575%2Fab50e8

[5] K. Beloy, W. F. McGrew, X. Zhang, D. Nicolodi, R. J. Fasano, Y. S. Hassan, R. C. Brown, and A. D. Ludlow, "Modeling motional energy spectra and lattice light shifts in optical lattice clocks," *Phys. Rev. A*, vol. 101, p. 053416, May 2020. Online: https://link.aps.org/doi/10.1103/PhysRevA.101.053416

[6] C. Grebing, A. Al-Masoudi, S. Dörscher, S. Häfner, V. Gerginov, S. Weyers, B. Lipphardt, F. Riehle, U. Sterr, and C. Lisdat, "Realization of a timescale with an accurate optical lattice clock," *Optica*, vol. 3, no. 6, pp. 563–569, Jun 2016. Online: http://www.osapublishing.org/optica/abstract.cfm?URI=optica-3-6-563