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Frequency evaluation of Maser 1401103 by IT-Yb1 for the period MJD 60734 to 60764

During the period MJD 60734 – 60764 (28 February 2025–30 March 2025) INRIM evaluated the frequency of the hydrogen maser IT-HM3 (BIPM code 1401103) 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. [3–5] 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-HM3. The frequency ratio between the ^{171}Yb transition and IT-HM3 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(HM1401103 /ITYb1) $/10^{-15}$	u_{A} $/10^{-15}$	u_{B} $/10^{-15}$	$u_{\mathrm{A/lab}}$ $/10^{-15}$	$u_{\mathrm{B/lab}}$ $/10^{-15}$	u_{Srep} $/10^{-15}$	Uptime
60734–60764	-371.20	0.00	0.03	0.14	0.02	0.19	37.2%

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

Effect	Rel. Shift/10^{-17}	Rel. Unc./10^{-17}
Density shift	1.33	0.04
Lattice shift	2.2	2.1
Zeeman shift	−2.83	0.02
Blackbody radiation shift (room)	−236.5	1.5
Blackbody radiation shift (oven)	−1.4	0.7
Static Stark shift	−0.22	0.08
Probe light shift	0.006	0.003
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	2361.7	2.7

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. [6]. Since 2025, IT-Yb1 implemented clock-line-mediated Sisyphus cooling [7] to reduce the temperature of atoms trapped in the lattice. This is expected to lower the uncertainty associated with the lattice shift; however, as we are still investigating it under these conditions, the presented results include a provisional larger uncertainty. The table includes the gravitational redshift relative to the conventional potential $W_0 = 62\,636\,856.0\,\mathrm{m^2 s^{-2}}$ [4].

3 Link evaluation

The uncertainty $u_\mathrm{l/lab}$ is due to the link between IT-Yb1 and IT-HM3, 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 and includes the maser distribution to the comb laboratory.

IT-Yb1 and the comb were operated for 964 483 s (uptime 37.2% of the evaluation period). The data collected and the distribution of the uptimes of IT-Yb1 are shown in Fig. 1. 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

Table 3: Uncertainty budget for the link between IT-Yb1 and IT-HM3 for the reported period.

Effect	Uncertainty/10^{-15}
Comb statistic	0.00
Distribution	0.05
Extrapolation (dead time)	0.13
Extrapolation (drift)	0.02
Total $u_{\mathrm{A/lab}}$	0.14
Optical/microwave comp. (type B)	0.02
Total $u_{\mathrm{B/lab}}$	0.02

correction for the maser drift. The maser drift of $-2.17(8) \times 10^{-16}$ 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. [8]. For this measurement we considered the IT-HM3 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

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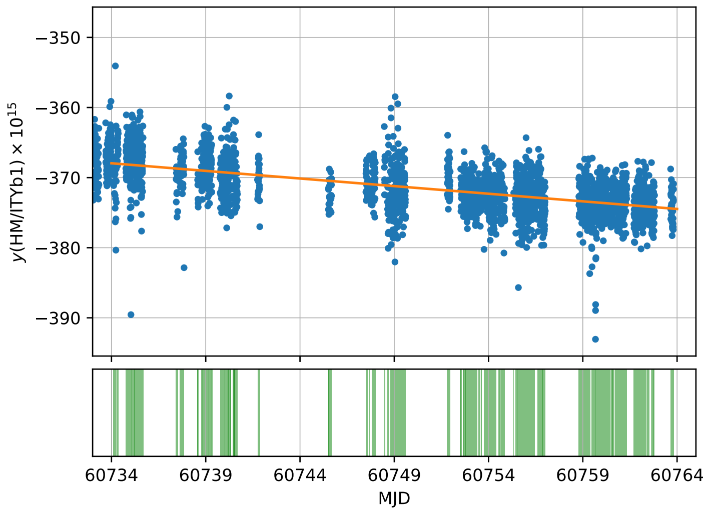

Figure 1: Fractional frequency deviation y(HM1401103/ITYb1) measured in the period MJD 60734 - 60764. Green shaded regions in the bottom plot represent the uptime of IT-Yb1.

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