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Frequency evaluation of Maser 1401104 by IT-Yb1 for the period MJD 59709 to 59724

During the period MJD 59709 – 59724 (10 May 2022–25 May 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
59709–59724	-235.3	0.04	0.25	1.9	0.2	1.9	16.9%

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

Effect	Rel. Shift/10^{-17}	Rel. Unc./10^{-17}
Density shift	-0.2	1.2
Lattice shift	0.6	1.2
Zeeman shift	-3.14	0.03
Blackbody radiation shift (room)	-234.5	1.3
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	2359.0	2.5

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)	1.9
Extrapolation (drift)	0.4
Total $u_{\mathrm{A/lab}}$	1.9
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 $W_0 = 62\,636\,856.0\,\mathrm{m^2 s^{-2}}$ [4].

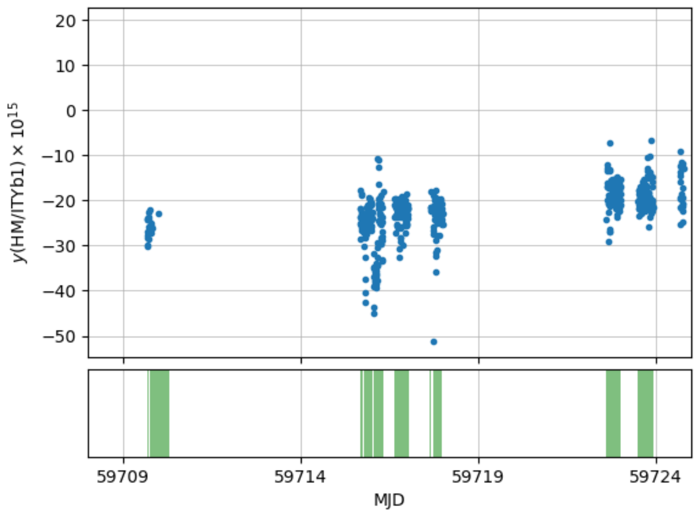

Figure 1: Fractional frequency deviation y(HM1401104/ITYb1) measured in the period MJD 59709 - 59724. Green shaded regions in the bottom plot represent the uptime of IT-Yb1.

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 218 506 s (uptime 17% 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 correction for the maser drift. The maser drift of $6.0(3) \times 10^{-16}$ /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

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