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Frequency evaluation of Maser 1401103 by IT-Yb1 for the period MJD 58419 to 58434

During the period MJD 58419 – 58434 (28 October 2018–12 November 2018) 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 recommended frequency for ^{171}Yb as a secondary representation of the second, $f(^{171}\text{Yb}) = 518\,295\,836\,590\,863.6$ Hz with a relative standard uncertainty of $u_{\text{Srep}} = 5 \times 10^{-16}$ [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-HM3. The frequency ratio between the ^{171}Yb transition and IT-HM3 is calculated from the comb measurement and from the corrections used for steering the acousto-optic modulator.

Table 1: Final evaluation using IT-Yb1

Period of estimation	y(HM1401103 /ITYb1)$/10^{-16}$	$u_\text{A}/10^{-16}$	$u_\text{B}/10^{-16}$	$u_{\text{l/lab}}/10^{-16}$	$u_{\text{Srep}}/10^{-16}$
58419–58434	-8961.0	<0.1	0.3	5.7	5

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

Effect	Rel. Shift/10^{-17}	Rel. Unc./10^{-17}
Density shift	-3.3	0.4
Lattice shift	6.0	1.8
Zeeman shift	-0.719	0.014
Blackbody radiation shift	-239.1	2.1
Static Stark shift	-2.0	1.1
Background gas shift	-0.5	0.2
Probe light shift	0.10	0.06
Others	0.0	0.6
Gravitational redshift	2599.5	0.3
Total	2360.0	3.1

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

Effect	$u_{\mathrm{l/lab}}/10^{-16}$
Optical/microwave comp. (type B)	0.8
Comb statistic	0.7
Extrapolation (dead time)	5.6
Extrapolation (drift)	0.6
Total	5.7

2 IT-Yb1 evaluation

The uncertainty u_{A} is the statistical contribution from the instability of IT-Yb1. It has been evaluated by interleaved measurements [4].

The uncertainty u_{B} is the systematic uncertainty of IT-Yb1. The systematic frequency shift and uncertainty budget of IT-Yb1 for the reported period are given in Tab. 2. The table includes the gravitational redshift relative to the conventional potential $W_0 = 62\,636\,856.0\,\mathrm{m^2s^{-2}}$ [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 between optical and microwave signals at the comb has a Type B uncertainty evaluated from comparison with a second comb. The statistical contribution from the comb is conservatively estimated from the

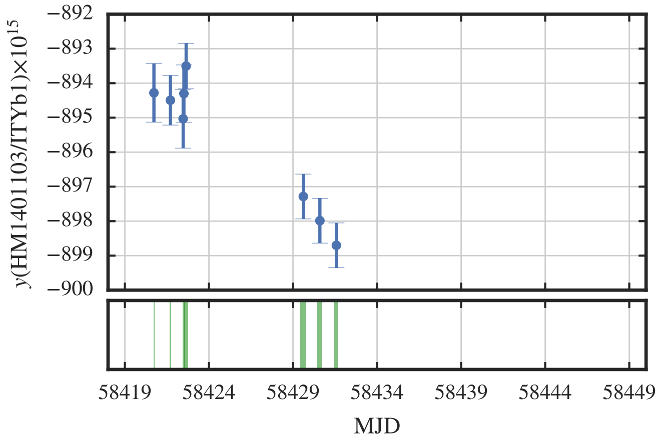

Figure 1: Fractional frequency deviation y(HM1401103/ITYb1) measured in the period MJD 58419 - 58434. Green shaded regions in the bottom plot represent the uptime of IT-Yb1.

instability of the observed noise and it includes the instability of the microwave frequency chain from the maser to the comb. The uncertainty from this instability is used to assign a weight to each frequency measurement.

IT-Yb1 and the comb were operated for a total of 91 970 s, with an uptime 7% 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 [4]. The drift of the maser has been calculated from a linear fit of IT-Yb1 data over the reported period and used to extrapolate the frequency to the center point. The contribution from dead times has been evaluated from simulations of the maser noise [4–6]. For this measurement the instability of IT-HM3 has been conservatively modelled as the quadrature sum of: white phase noise $1.5 \times 10^{-13}(\tau/\mathrm{s})^{-1}$; white frequency noise $3.5 \times 10^{-14}(\tau/\mathrm{s})^{-1/2}$; flicker frequency noise 6×10^{-16}; random walk frequency noise $<1 \times 10^{-18}(\tau/\mathrm{s})^{1/2}$.

References

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