Frequency comparison NRC-FCs2 – UTC(NRC)
For the period MJD 61039 - 61069

Frequency comparison of the Cs fountain primary frequency standard NRC-FCs2 have been made with respect to UTC(NRC) during evaluation campaign of MJD 61039 - 61069. Table below summarizes the evaluation result as well as the associated uncertainties.

Evaluation period (MJD)	61039 - 61069
Fractional uptime	90.4%
y(FCs2- NRC) [10^{-16}]	-4.13
u_A (1 σ) [10^{-16}]	1.3
u_B (1 σ) [10^{-16}]	1.0
u_{A_lab} (1 σ) [10^{-16}]	1.2
u_{total} [10^{-16}]	2.0

Methods

The influence of systematic effects was investigated in [1,2,3]. The effects for which NRC-FCs2 is corrected are:
- 2^{nd} order Zeeman effect
- blackbody radiation
- relativistic shifts
- cold collisions
- microwave lensing
- microwave leakage
- distributed cavity phase shift

Several other systematic effects did not produce a measurable bias (and are therefore uncorrected for), but do contribute to the overall uncertainty of FCs2 and are included in the uncertainty budget.
The cold collisional shift was actively corrected for by toggling the operation of the fountain between high and low densities and extrapolating the measured frequencies to zero density. The type B uncertainty of the collisional shift is due to the uncertainty in the ratio of high density to low density. A full uncertainty budget for the evaluation period of MJD 61039 - 61069 is given in Table 2.

The operating procedure of FCs2 is described in detail in [1]. The measurements of FCs2 are related to the H-maser 1400307 (designated as VM1), as it is used to lock the timebase of the synthesizer producing the microwaves used to interrogate the atoms in the fountain clock. The maser is located in the same building but in a separate room from FCs2, and a 5 MHz signal from the maser is brought across a hall to the fountain clock lab to provide a frequency reference for the synthesizer used to generate our Ramsey microwaves. The average fractional frequency difference for each evaluation period, y(FCs2 – VM1), is evaluated from a linear fit of the 2-hour averaged data. The averaged fractional frequency difference between UTC(NRC) and VM1, y(NRC – VM1), is also calculated for the same period of the evaluation. Therefore, the fractional frequency difference between FCs2 and UTC(NRC) is calculated by taking the difference of y(FCs2 – VM1) and y(NRC – VM1).

Uncertainties

Short-term stability and type A uncertainty

The typical short-term stability of FCs2 for the collisional shift-corrected frequency was 1.75 x 10^{-13} after 1 second of averaging. The reported values of the type A uncertainty, u_A, assume white FM as the dominant noise source during the averaging period. The averaging period is calculated as (reporting period – dead time).

Type B uncertainties

The accuracy of NRC-FCs2 has been re-evaluated in 2025 and the details can be found in [2]. Specifically, the cold collisional frequency shift uncertainty has been reduced significantly by characterizing the atom cloud density ratio uncertainty using absorption imaging [3]. In this report, the blackbody radiation shift and the associated uncertainty were evaluated based on

$$\frac{\Delta f_{BBR}}{f_0} = \frac{k_0 E_{300}^2}{f_0}\left(\frac{T}{T_0}\right)^4\left(1+\epsilon\left(\frac{T}{T_0}\right)^2\right)$$

where T is the ambient temperature in kelvin, T_0 = 300 K, E_{300} = 831.9 V m^{-1} is the root-mean-square blackbody radiation electric filed at 300 K, k_0 = -2.282(4) x 10^{-10} Hz (V $m^{-1})^{-2}$ [4], ϵ = 0.013(1) [5], and f_0 is the Cs transition frequency. The gravitational redshift is calculated using the CVGD2013 geoid model which uses a reference potential of W_0 = 62 636 856.0 m^2/s^2. It is reported, in combination with the 2nd order Doppler shift, as Relativistic Effects.

Link to local timescale

The uncertainty of the link with our local timescale, u_{A_Lab}, is the quadratic sum of two terms: the first term is the uncertainty in the frequency transfer between the maser 1400307 and FCs2, and the second term is the result of measurement dead time. In FCs2, the former uncertainty is attributed to phase fluctuations in cables between H-maser 1400307 and FCs2 and is estimated to be no larger than 10^{-16}. The phase difference between H-maser 1400307 and UTC(NRC) is continuously measured using a TimeTech multichannel time interval counter whose noise contribution is negligible for the duration of this evaluation period.

The effects of measurement dead time arise due to both scheduled and unscheduled interruptions in the fountain operation. The unscheduled interruptions were rare, and generally caused by a failure in laboratory environmental control, or a broken laser lock. The contribution of dead time to the uncertainty is estimated using a numerical simulation that models the measurement noise as having two contributions: white FM (1.75 x 10^{-13} $\tau^{-1/2}$) and flicker FM (2.0 x 10^{-16}) [1].

Evaluation period (MJD)	61039 - 61069	
Physical effect	Bias [10^{-16}]	Uncertainty [10^{-16}]
Zeeman effect	724.263	0.2
Blackbody radiation	-163.153	0.36
Relativistic effects	104.45	0.03
Cold collisions	-	0.41
Background gas	-	< 0.1
AC Stark	-	< 0.1
Rabi, Ramsey pulling	-	< 0.1
Cavity pulling	-	< 0.1
Majorana transitions	-	< 0.1
DCP m=0	0.06	0.34
DCP m=1	-	0.4
DCP m=2	0.04	0.02
Microwave lensing	0.6	0.2
Microwave leakage	-	0.2
Microwave spectrum	-	< 0.1
Synchronous phase transients	-	0.5
Total	666.26	1.0

Table 2. Contributions to type B uncertainty for FCs2 for period MJD 61039 - 61069. The bias due to cold collisions is corrected actively by toggling between high and low densities and extrapolating to zero.

References:

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