FREQUENCY COMPARISON (H_MASER 140 0890) - (LNE-SYRTE-FO2)
For the period MJD 54779 to MJD 54794

The primary frequency standard LNE-SYRTE-FO2 has been compared to the hydrogen Maser 140 0890 of the laboratory, during a measurement campaign between MJD 54779 and 54794 (9th November 2008-24th November 2008). The fountain operation covers ~ 78 % of the total measurement duration.

The mean frequency difference at the middle date of the period is given in the following table:

Period (MJD)	Date of the estimation	y(HMaser$_{140\ 0890}$ – FO2)	u_B	u_A	$u_{link\ /\ maser}$
54779 – 54794	**54786.5**	**-774.7**	**6.2(*)**	**2**	**1.1**

Table 1: Results of the comparison in 1 x 10^{-16}.

The FO2 fountain was operated in the same mode during all the period: the interrogating signal synthesis is based on the down conversion to 9.192 GHz of a 11.98 GHz signal provided by a cryogenic oscillator phase locked to the maser 140 0890. It uses a synthesizer to lock the microwave signal on the atomic resonance. The frequency difference between this maser and the fountain is deduced from the average correction applied to the synthesizer.

(*) During this period, the FO2 Cs fountain operated at full Cs density over the last 5 days while, as usual, over the first 10 days measurements were performed at full/half density in interleaved configurations. For this reason the systematic uncertainty affecting the cold collision shift correction is larger than reported previously. For a detailed account, see § Accuracy below.

Average value and statistical uncertainty

This paragraph describes the calculation of the average frequency of HMaser$_{140\ 0890}$-FO2. The details of the calculation are given in figure 1:

The frequency data averaged over 0.2 day are plotted on the upper graph (blue points) together with a linear unweighted fit (red line).
The parameters of the fit y=a + bx are respectively:

Period (MJD)	a	b
54779 – 54794	**(26.6 +/- 1.6) 10^{-12}**	**(-4.9+/- 0.3) 10^{-16}/day**

Table 2: Coefficients of the linear fit of HMaser$_{140\ 0890}$-FO2

These coefficients are used to remove the drift (data plotted in the graph in the middle, red points) and to calculate the average value at middle date, given in table 1. The lower graph gives the variance of the frequency residuals. We estimate a statistical uncertainty $u_A = 2\ 10^{-16}$.

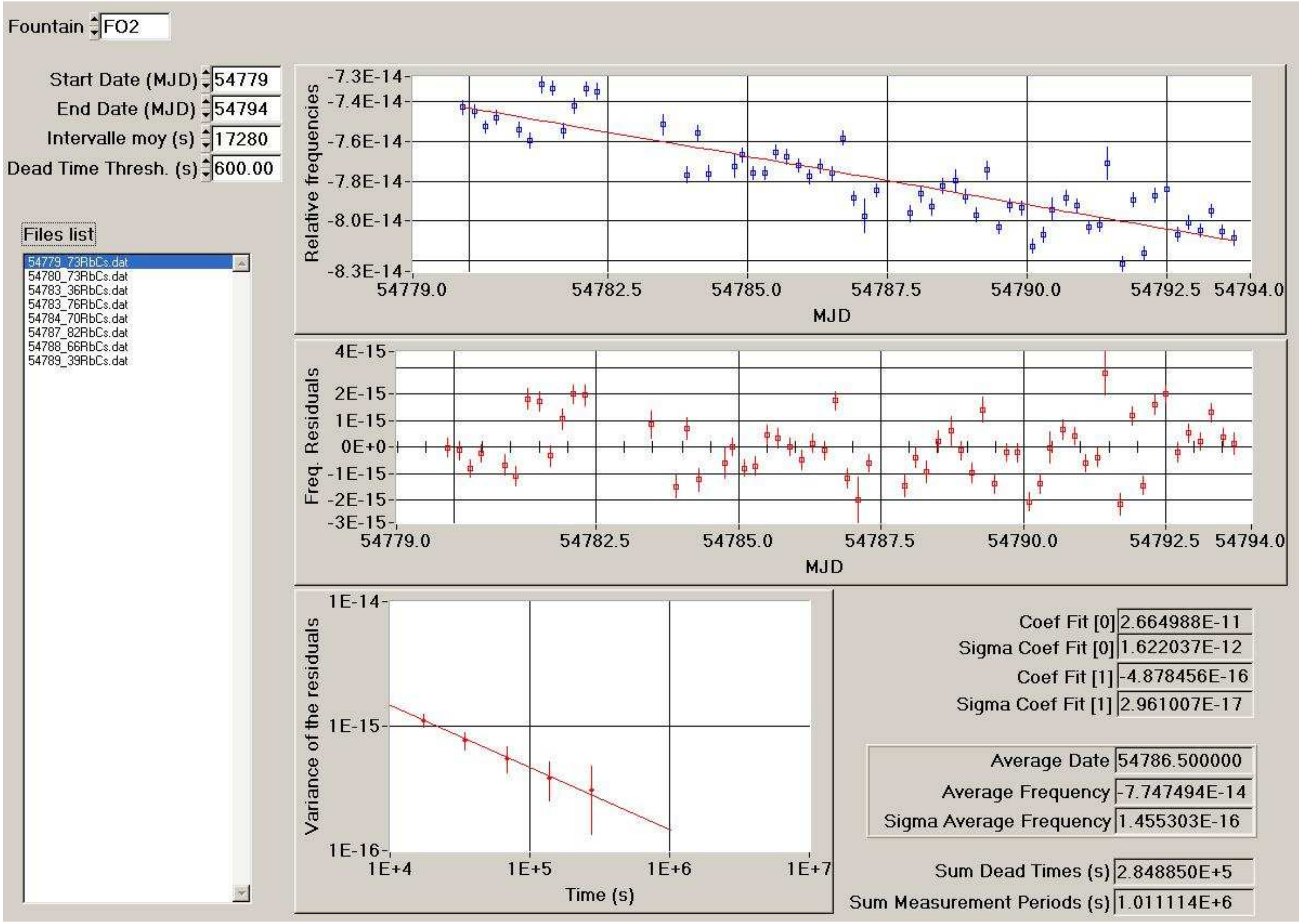

Figure 1: Processing of the data HMaser$_{140\ 0890}$-FO2 for the period MJD 54779-54794

We verified the result by applying a second method. We calculated the accumulated phase by integrating the data points, assuming a linear frequency drift during each segment, and during the dead times of the fountain operation. The average frequency is then obtained by dividing the total accumulated phase by the calibration period duration. The processing has been performed with segments of 0.01, 0.1 and 1 day durations. The differences between the results and the value given in table 1 are in agreement within $2\ 10^{-16}$, which is consistent with the estimations of the statistical uncertainty u_A and the uncertainty due to the link.

Accuracy

The frequency is corrected from the quadratic Zeeman, the Black Body radiation, the cold collisions and cavity pulling, and the red shift effects. In this 15 days long period, during the last 5 days, the FO2 Cs fountain operated always at full Cs density, and for the first time with Rb atoms launched synchronously, which unusually prevented us from a real-time correction for the cold collision shift. This shift has been corrected by extrapolating the cold collision coefficient based on previous and subsequent measurements performed, as usual, at full/half density. The relative uncertainty on the correction for this data subset is estimated as 10^{-15}, while it is estimated as 2.5×10^{-16} for the first 10 days period using the usual approach (see previous report). For the whole period, we take a ponderated uncertainty (5×10^{-16}). During the same period the FO1 SYRTE fountain operated simultaneously too. There is no significant change in the FO1-FO2 difference over the two subperiods (MJD 54779 to MJD 54789 and MJD 54789 to MJD 54794).
Table 3 below summarizes the budget of systematic effects and their associated uncertainties. The accuracy is the quadratic sum of all the systematic uncertainties.

	Correction (10^{-16})	**Uncertainty (10^{-16})**
Quadratic Zeeman effect	-1914.3	0.3
Black body radiation	167.8	0.6
Cold collisions and cavity pulling	259	5.0
First order Doppler	0	< 3.0
Microwave spectral purity&leakage	0	<0.5
Ramsey & Rabi pulling	0	< 0.1
Microwave recoil	0	< 1.4
Second order Doppler effect	0	< 0.1
Background gas collisions	0	<1.0
Total	**-1487.5**	**6.1**
Red shift	- 65.4	1.0
Total with red shift	**-1552.9**	**6.2**

Table 3: Budget of systematic effects and uncertainties for SYRTE-FO2 fountain for the MJD 54779-54794

$$u_B = 6.2 \times 10^{-16}$$

Uncertainty of the link

The uncertainty of the link is the quadratic sum of 3 terms:
-A possible effect of phase fluctuations introduced by the cables that connect the primary standard to the Maser. It is estimated to be 10^{-16}.
-The uncertainty due to the dead times of the frequency comparison.
To estimate this contribution, we use the comparison between the reference Maser and Maser 140 0889. We calculate the time deviation of the normalized phase differences with the linear frequency drift removed. The uncertainty is given by:

$$\sigma_{y_{Dead\ Time}} = \frac{\sqrt{\sum_i \sigma_{x_i}^2}}{T}$$

where σ_{xi} are the extrapolated TVar for each dead times. We applied the method to the dead times longer than 600 s and obtained stability degradation of $0.4 \ 10^{-16}$.