ALMA Memo 514
Saturation correction with atmospheric fluctuations

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January 20, 2005

Abstract

We revisit memo 461 by taking into account the fluctuations of J_{sky}. A calibration precision of 1% is achievable at millimeter wavelengths. For sub-millimeter wavelengths a precision of 2 to 3 % at most can be achieved. In order to obtain such precisions, receiver stability is essential. These numbers should however be taken with some caution as the atmospheric fluctuations may differ from the values assumed here and the calibration device switch faster. This memo shows that noise may not be the limiting factor in the calibration process.

1 Introduction

In Memo 461, we had proposed a five position measurement system in order to improve the calibration precision in presence of saturation. A measurement noise of 0.1 K had been applied. In the present Memo, we reevaluate the precision of the calibration taking into account (hopefully) realistic fluctuations of the sky temperature δJ_{sky}.

2 Fluctuations of Sky Temperature

Assuming a frozen screen approximation and according to Memo 371 equation (17), the rms sky temperature fluctuations δJ_{sky} can be expressed as:

$$\delta J_{sky} = \kappa(\nu)\sigma_w \left(\frac{\Delta l}{300}\right)^{0.6} \tag{1}$$

where the same notations as in Memo 371 have been used, i.e.
$\kappa(\nu)$ is the ratio of water emission to pathlength fluctuations (in mK/μm)
σ_w is the atmospheric path rms fluctuations on a 300 m baseline. The median is $\sigma_w = 250\,\mu$m.
D is the antenna diameter
Δl is the effective length over which the fluctuation occurs. For calibration, $\Delta l = vt$, with v the wind speed and t the time between 2 operations.

Table 1: Sky temperature J_{sky}, ratio of water emission to pathlength fluctuations $\kappa(\nu)$, and sky temperature fluctuations δJ_{sky} for typical weather conditions at the given frequencies.

Frequency (GHz)	Water (mm)	T_{atm} (K)	J_{sky} (K)	$\kappa(\nu)$ (mK/μm)	δJ_{sky} (K)
90	1.5	10	50	$\ll 1$	$\ll 0.033$
280	1.0	40	110	2.3	0.076
350	1.0	70	130	6.0	0.20
650	0.5	105	180	23	0.76

The above equation is valid providing that $vt \geq D$; for shorter timescales, the antenna filters out effectively the fluctuations.
For $t = 1\,\mathrm{s}$ and $v = 10\,\mathrm{m\,s^{-1}}$, the pathlength fluctuations are of the order of 33 μm.

Fig. 2 of Memo 371 gives $\kappa(\nu)$ as a function of frequency. Table 1 lists the derived δJ_{sky} for $t = 1\,\mathrm{s}$ and $v = 10\,\mathrm{m\,s^{-1}}$.

In the above, dynamical scheduling was assumed, i.e. the observing frequency was matched to the weather conditions (cf. column 2 of Table 1).

3 Dependency of the gain on the coupling coefficient, in the case of saturation correction

We have rerun our model (Memo 461, section 6) evaluating the achievable precision the gain for a given precision on the coupling coefficient, for the "optimum" setup (i.e. 5 load calibration system). This was done supposing the path fluctation rms given in Table 1 and for 2 values of the measurement noise.

Fig. 1, 2, 3 and 4 present the results for 90, 280, 350 and 650 GHz and a measurement error of 0.1 K.

For 90 GHz (Fig. 1), a 1% precision on the gain is reachable if the coupling coefficient is known to within 0.01. At 280 GHz, the coupling coefficient should be known to within 0.005. At 350 GHz, a precision of around 2% can be expected if f is known to within 0.01. For 650 GHz however, a precision of better than $\sim$3% cannot be expected, since the fluctuations (measurement noise and path length fluctuations) is the main factor limiting the precision.

Fig. 5 shows the results for 90 GHz and a measurement error of 0.33 K. A precision of 1% on the gain is barely reachable at 90 GHz, since the gain estimates start being dominated by noise. For higher frequency it only gets worse.

4 Conclusions

Using the five position calibration system described in Memo 461, it is possible to reach a calibration precision of 1% at millimeter wavelengths, providing the coupling coefficient f between the charges is known to better than 0.01 (i.e. 2%) at millimeter wavelengths and better than 0.005 towards 280 GHz. At 280 GHz, the saturation correction should improve the precision of the calibration. For sub-millimeter wavelengths, a precision of 2% at 350 GHz and 3% at most can be expected to be achieved. For 650 GHz, the saturation plays no role. In order

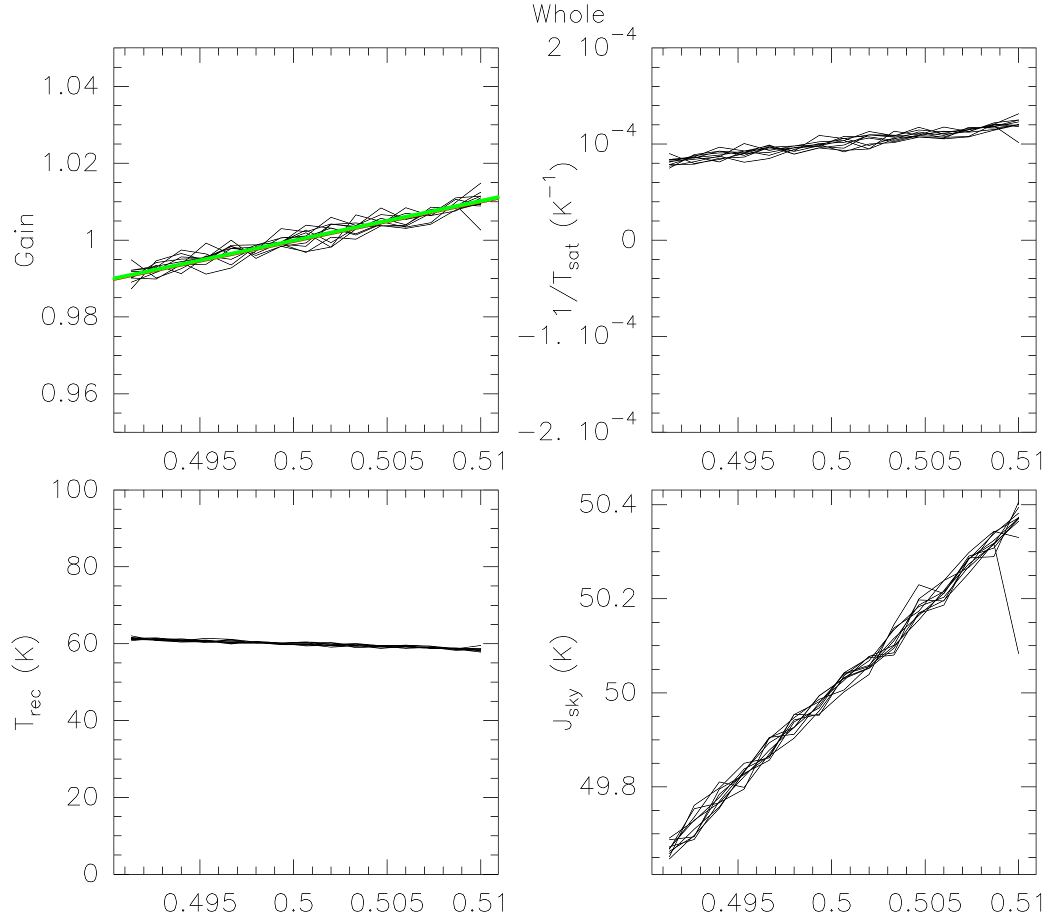

Figure 1: Expected dependency of the receiver temperature (input value 60 K), gain (input value 1.00), saturation value (input value 10^{-4}), and effective atmospheric noise power (input value: cf. column 4 of Table 1) as a function of the coupling coefficient between the ambient and hot load (input value $f = 0.5$), **for a frequency of 90 GHz.**

to reach these calibration precisions, it is essential to achieve receiver stabilities of $\sim 3.10^{-4}$ (noise measurement $< 0.1\,\mathrm{K}$) on seconds timescales.

We recall that when saturation can be neglected ($T_{sat} \gg 10^4\,\mathrm{K}$), a better precision can be obtained using only 3 positions: hot, ambiant and sky.

All of the estimates above are to be taken with some care. On the one hand, the atmospheric fluctuations may be larger. On the other hand, the calibration device may switch faster. This memo just shows that noise is probably not the limiting factor in the calibration precision.

References

[Guilloteau & Moreno, memo 371]
Moreno, R., & Guilloteau, S. 2001,
Receiver Calibration Schemes for ALMA
ALMA memo 371

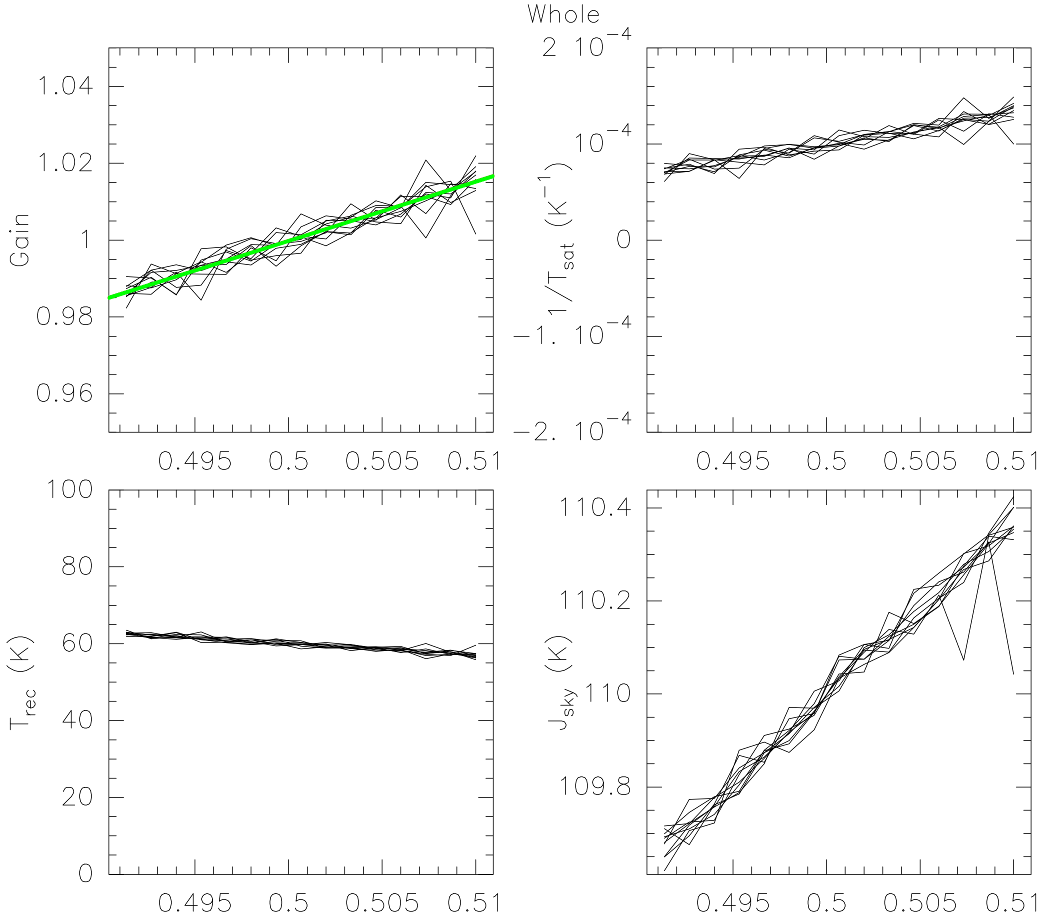

Figure 2: Same as Fig.1 but for a frequency of 280 GHz

[Guilloteau & Bacmann, memo 461]
Guilloteau, S. & Bacmann, A. 2003,
The Amplitude Calibration System revisited
ALMA memo 461

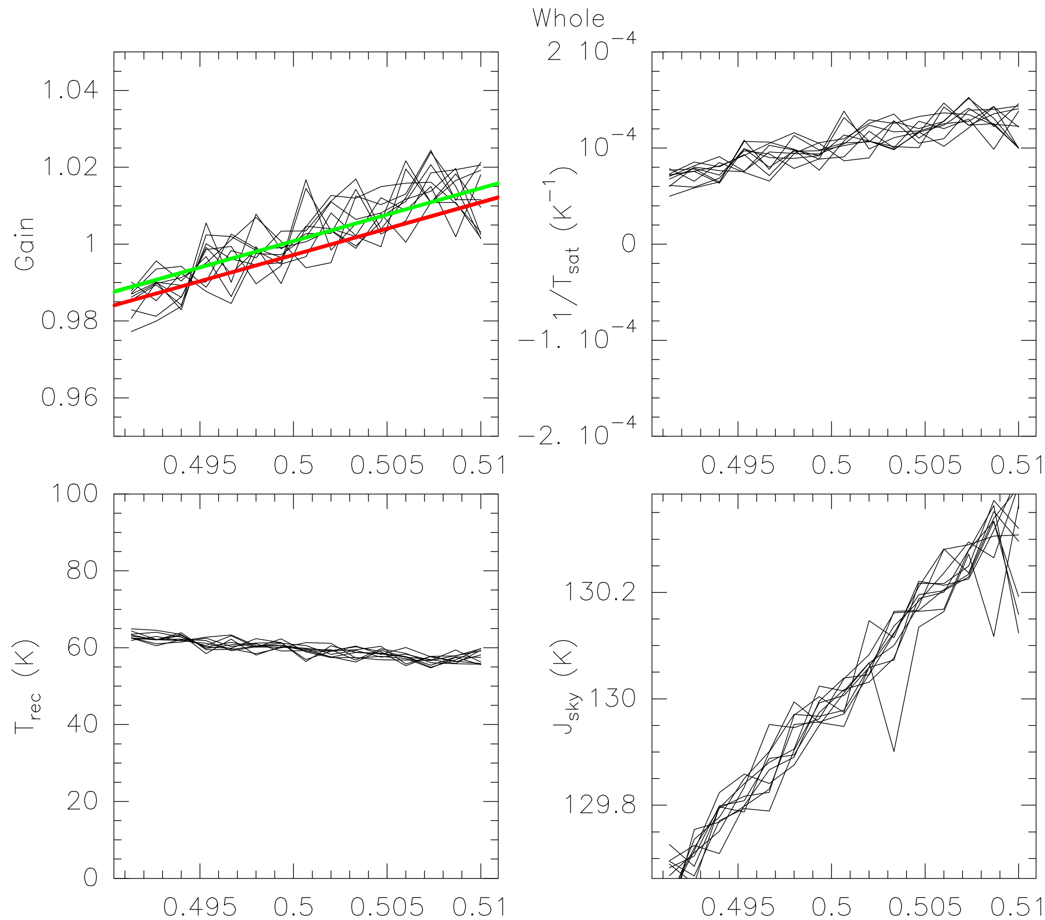

Figure 3: Same as Fig.1 but for a frequency of 350 GHz

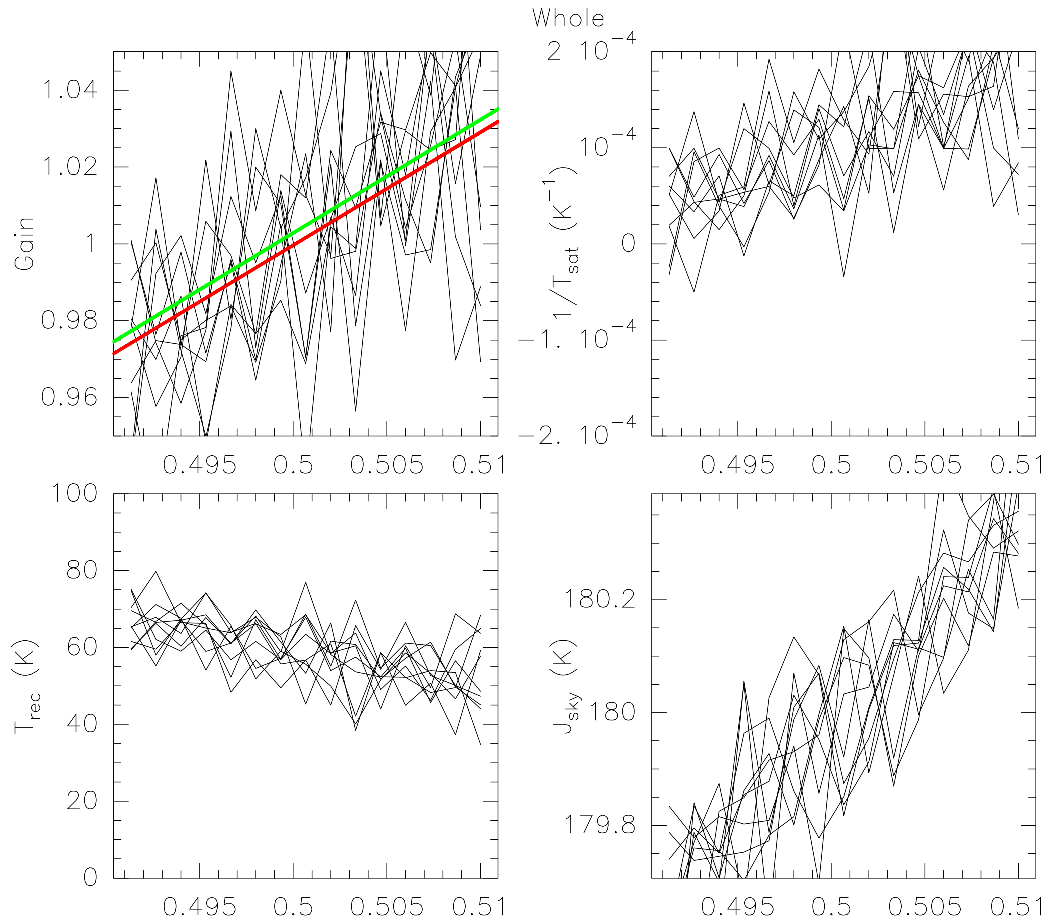

Figure 4: Same as Fig.1 but for a frequency of 650 GHz

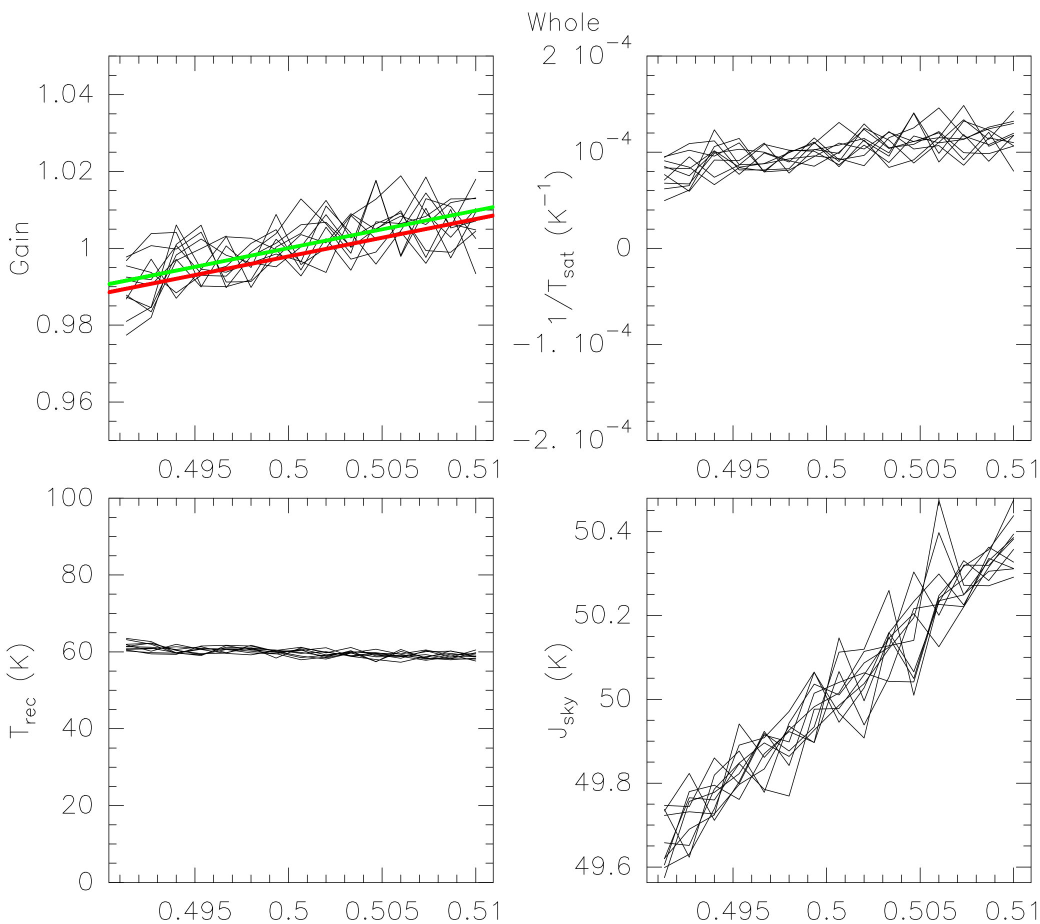

Figure 5: Same as Fig.1 but for a noise measurement of 0.33 K instead of 0.1 K (corresponding to a receiver stability of $\sim 10^{-3}$)