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ALMA calibration – example of scientific impact

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Abstract

An example of the scientific impact of band-to-band calibration errors for ALMA is presented. The specific example entails constraining the temperature of a modified black body at high redshift. This experiment is one of the key goals in the study of the dust obscured star formation history of the universe. We find that 3% calibration errors between 250 and 350 GHz will constrain (at 3σ) the temperature of a warm ($\sim$ 50 K) dust component to only 20^o, while 10% calibration errors between 250 and 650 GHz provide a 3σ constraint of 10^o.

keywords: ALMA calibration; galaxies – star forming, high redshift; dust – spectral energy distribution

The issue has been raised as to the scientific impact of gain calibration errors on ALMA science. The scientific advisory committee has considered this issue in a broad sense through the Design Reference Science Plan (DRSP)[1]. In this memo I investigate this issue in more detail using an important scientific program as a specific example.

The science program considered entails constraining the temperature of modified black body emission from warm dust associated with a high redshift star forming galaxy. The dust-obscured star formation history of the universe is one of the key science drivers for ALMA, and the dust temperature is one of the crucial parameters in this study. I emphasize at the start that these results are meant to be illustrative, not definitive. As such, I explore only a limited range in parameter space, directly relevant to high-z, active star forming galaxies. And for simplicity, I assume a single dust temperature model with temperatures in the range 50 K to 70 K, a dust emissivity index $\beta = 1.5$ (Yun & Carilli 2002), and a single redshift ($z = 4$).

Figure 1 shows example modified black body spectra in the range 50 K to 70 K in the rest frame of the source. Also indicated on the plot are the source-frame frequencies corresponding to ALMA bands 6, 7, and 9 (250, 350, 650 GHz) redshifted to $z = 4$. All spectra have been normalized at band 6. Also shown are $\sigma = \pm 3\%$ and $\sigma = \pm 10\%$ error bars at band 7 and band 9. These error bars give the sense of how well the differences in thermal models are constrained using observations at the different ALMA bands.

Table 1 gives quantitative estimates of the constraints on dust temperature in the relevant range. We find that 3% calibration errors between 250 and 350 GHz only provide a 3σ constraint of 20^o to the dust temperature. Including 650 GHz clearly helps, due to the larger frequency spread and higher frequency (closer to the black body peak). However,

[1] see www.strw.leidenuniv.nl/alma/drsp-calib-prlim.html

gain calibration will be more difficult at 650 GHz, so we consider the results for 10% calibration errors between 250 and 650 GHz in Table 1. In this case, a 10^o temperature difference can be constrained to about 3σ.

What temperature constraint is 'good enough' for the science? For a modified black body of emissivity index β, the dust mass derived from a single flux density measurement in the Raleigh-Jeans regime is $\propto$ T^{-1}. Hence the dust mass changes by about 30% for a model temperature change of 50 to 70 K. This change is probably acceptable for most scientific purposes. However, the integrated IR luminosity is a much stronger function of temperature, $L_{IR} \propto T^{3+\beta}$. Hence, a model temperature change from 50 to 70 K leads to a factor 4.5 change in derived IR luminosity. This factor is comparable to the large and uncertain dust-extinction corrections applied to optical observations of high redshift star forming galaxies (Calzetti 2001), and hence is not an acceptable scientific goal for constraining the dust-obscured star formation history of the universe. If we want to get the luminosity error below a factor 2, we require a temperature error $<$ 8K.

As a final note, we briefly consider ALMA sensitivity limits in the context of the gain errors quoted above. The typical submm galaxy flux density at 350 GHz is $\sim$ 5 mJy (Blain et al. 2002). These correspond to galaxies with IR luminosities of $L_{FIR} \sim 5 \times 10^{12}$ $L_\odot$, or star formation rates of order 10^3 $M_\odot$ year^{-1}. Such a source could be detected with a SNR = 30 in 0.6 hours with ALMA. The Ly-break galaxies, perhaps more representative of the star forming galaxy population at high redshift, are typically an order of magnitude fainter at 350 GHz, with star formation rates of order 10^2 $M_\odot$ year^{-1} (Chapman et al. 2000). Constraining the thermal spectral energy distributions of these sources will require deep fields ($\sim$ 60 hrs) in order to obtain high SNR ($>$ 30) detections.

Table 1: Temperature constraints

Cal. error	ΔT = 5 K	10 K	20 K
$\pm$3% 250 to 350 GHz	1.1σ	2.1σ	3.2σ
$\pm$10% 250 to 650 GHz	1.5σ	2.7σ	4.4σ

Blain, A. et al. 2002, Phys. Rep., 369, 111

Calzetti, D. 2001, New AR, 45, 601

Chapman, S. et al. 2000, MNRAS, 319, 318

Yun M.S. & Carilli, C. 2002, ApJ, 568, 88

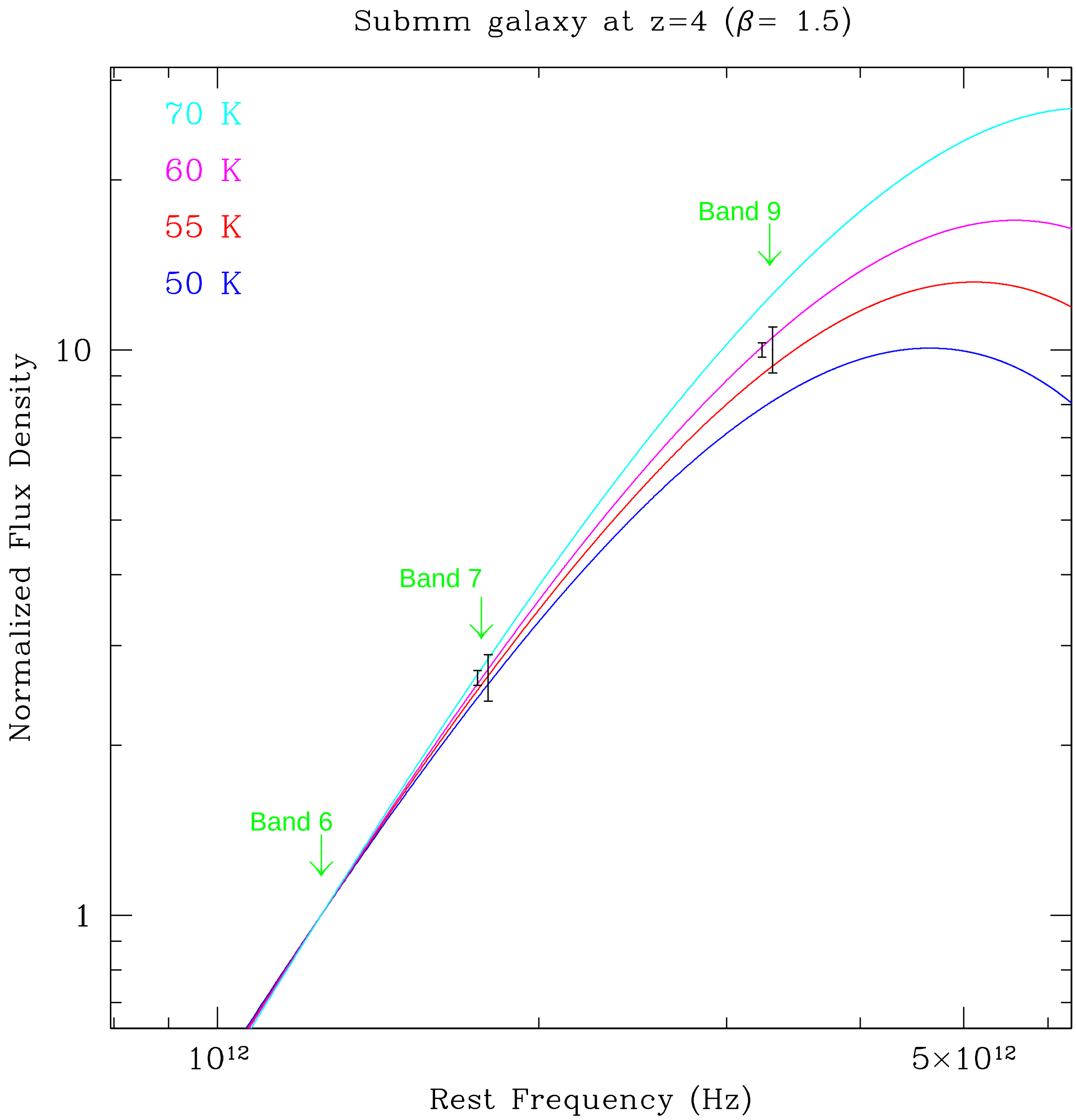

Fig. 1.— Modified black body spectra (rest-frame frequencies) with $\beta = 1.5$. The ALMA bands 6, 7, 9 are shown redshifted to $z = 4$ (corresponding to observing frequencies of 250, 350, and 650 GHz, respectively). The error-bars for bands 7 and 9 correspond to $\pm 3\%$ and $\pm 10\%$ calibration errors with respect to 250 GHz. All spectra are normalized at 250 GHz.