FXavier Désert, N. Ponthieu, Work memo on skydip in NIKA2 idl pipeline, May 2021

1 The problem

The skydips are processed all together for a given campaign. They give very accurate results for the opacity measurements (1% precision) but there is one nagging question which is the ratio τ_2/τ_3 between the 2 and 1 mm channels. This ratio is above the ATM predicted ratio by almost a factor almost 50 %. Here is the evidence on Fig. 1.

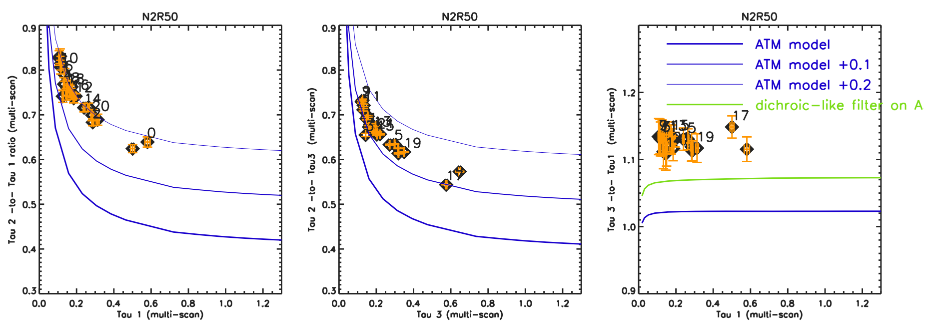

Figure 1: Standard output of the IDL pipeline skydip reduction, here for the run N2R50 (20 scans)

Here we remind the equations for skydips to understand a possible way out.

The resonance frequency f_r is linearly related to the total power on the kid, as represented by the equivalent temperature T_{sky}:

$$f_r = f_0 - B\,T_{sky}$$

where f_0 is the zero-load frequency and B is the response to total beam in Hz/K.

The equivalent sky temperature is proportional to the total power on the Kid so that:

$$T_{sky} = T_{atm}\frac{\int d\nu\, b_\nu(1-\exp(-\tau_\nu/\sin el)}{\int d\nu\, b_\nu},$$

where T_{atm} is the mean atmosphere temperature (usually taken as a fiducial temperature of 270 K), b_ν is the transmission (including the RJ ν^2 which is compensated by the étendue), τ_ν is the zenith sky opacity and el is the current skydip elevation (and the airmass is $am = 1/\sin el$). In the standard skydip hypothesis, the opacity is rather constant across the filtering bandpass of the Kid (including the filters) so that we can drop the integral and get:

$$T_{sky} \simeq T_{atm}(1-\exp(-\tau/\sin el)).$$

If the opacity is small, the degeneracy of the response B with the opacity τ is large. When τ is large, one can distinguish (with a non-linear fit) the influence of the response and the opacity.

2 Testing hypotheses

Here we numerically try to twist the modeling hypotheses in order to be compatible with the skydip data.

2.1 Attempt 1

Fig. 2 shows (top-left) the NIKA2 bandpasses, along with the atmospheric oxygen (green) and the water vapour (yellow) opacities. On the top-right the integrand of the atmosphere emission times the transmission $b_\nu(1-\exp(-\tau_\nu/\sin el)$, is shown (oxygen and water separated). Oxygen is contributing to the lower frequencies whereas the water vapor contributes to the higher frequencies. The bottom-right figure (black curve) shows the expected behaviour of the 2 to 1-mm opacity ratio. At low opacities, it rises because the oxygen becomes the dominant factor and oxygen contributes to the 2 mm more than to the 1 mm. This is the trend seen in the real data (dots), but they disagree wildly at large opacities (the ratio is 20% higher than expected (thin black curve) at large opacities).

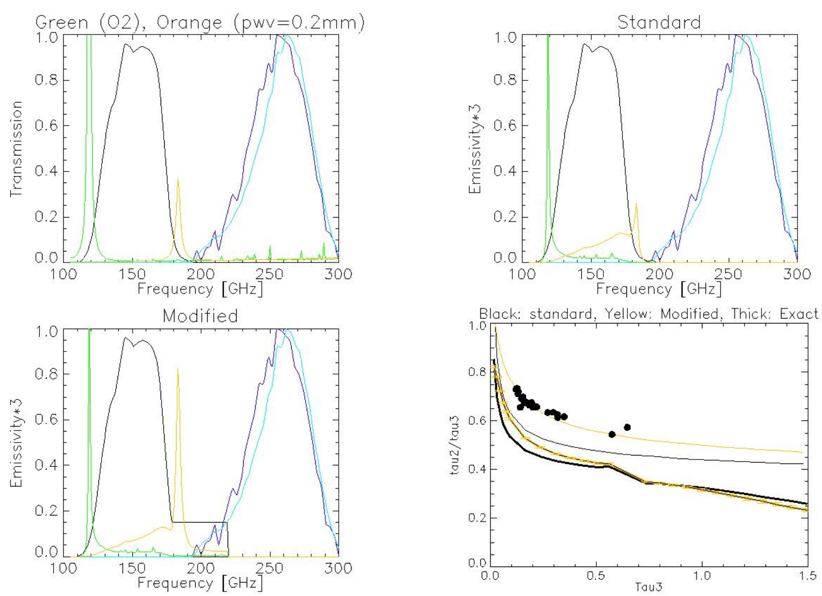

Figure 2: Modified modeling of the bandpasses. The 2mm bandpass is modified with a Heaviside-like function at 0.13 between 170 and 220 GHz.

The bottom-left figure shows one way out. We trick the bandpass (black curve). In that case the strong water vapour line at 180 GHz increases the opacity. By playing with the cutoff frequency (220 GHz) and the level of the leak (0.13) we fit reasonably well the data points on the bottom-right plot with the yellow thin curve. The problem is really that now the modified 2 mm bandpass is way off the bandpass measurements. We retain from that that there is a real issue in the 2mm band. The problem is even worse than the thin yellow curve suggests because each black dot is the result of one skydip analysis. It is not just the opacity at 2mm against the 1mm opacity: the whole airmass range from 60 down to 18 degrees is used. We have simulated that in a non-linear fit where the opacity is the only unknown and the results are shown as thick lines (called exact). The yellow thick curve is obtained for the modified bandpass. It is close to the black curve and not anymore to the data. What is happening is that we 'average' the opacity to the right with a range of 2 to 3 in opacity. Thus this is lower (thick yellow curve) than the thin yellow curve. So we are back to square one.

2.2 Attempt 2

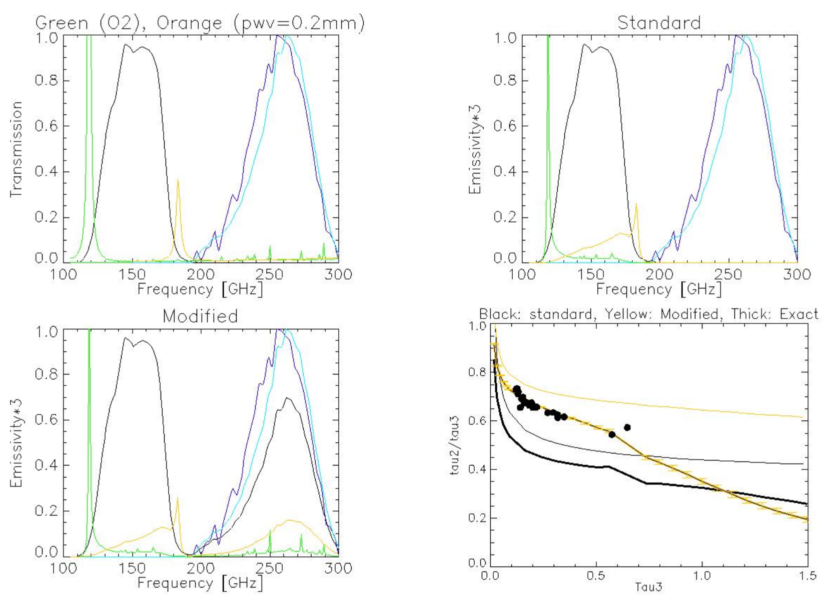

Figure 3: The 2mm bandpass is modified by adding the 1mm bandpass. REDO figure

Here, in Fig. 3, we have added 70% of the 1mm bandpass to the 2mm bandpass. The idea could be that some 1 mm light does not follow the expected optical path and somehow reaches the 2 mm detectors. The correction factor is really outrageous and, again, would have been measured with the lab bandpass measurement.

2.3 Attempt 3

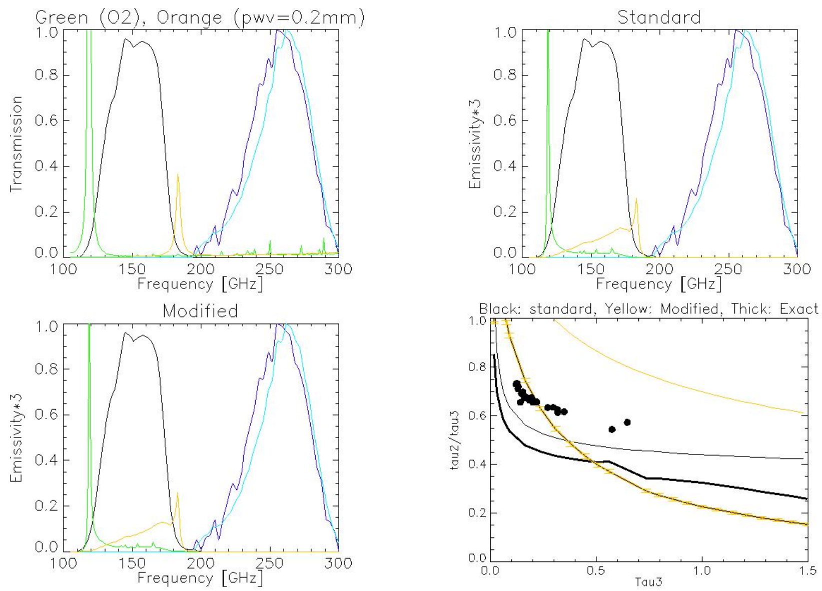

Figure 4: Modified modeling of the bandpasses. The 2mm bandpass is modified by adding a 'leak' of 30 % between 300 and 350 GHz. REDO

Here, in Fig. 4, we have added some 850 μm transmission. Results are poor.

2.4 Attempt 4

Here, in Fig. 5, we assume that there is a large spillover at 2 mm. This is how we model that effect:

$$T_{sky} = T_{atm} \frac{\int d\nu\, b_\nu (1 - \exp(-\tau_\nu / \sin el)}{\int d\nu\, b_\nu} (1 - \alpha \cos el) + \alpha \cos el T_{ground},$$

where α is the spillover factor (we fit at 15 %) and T_{ground} is the Earth emission temperature entering the telescope (we took $T_{ground} = T_{atm}$). The fit is poor.

2.5 Attempt 5

There could have been a misinterpretation of the integrand of the skydip equation so we model a tilt in the bandpass with a power-law correction factor in $(\frac{\nu}{150\,\mathrm{GHz}})^2$. That does not help (see Fig. 6).

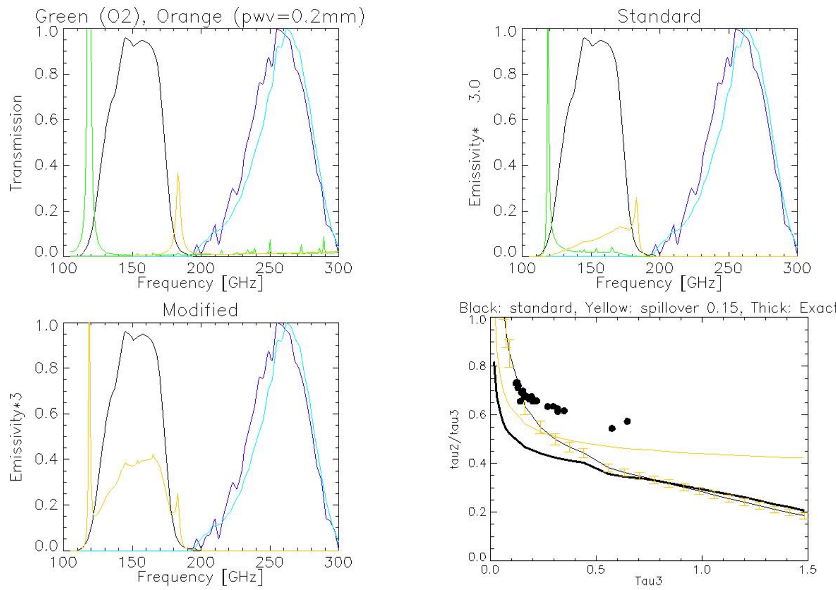

Figure 5: A large spillover is added to band 2.

2.6 Attempt 6

In the case in Fig. 7, the (continuum) emissivity of the water vapour is increased by 1.55 in the 2 mm band (we left the 1 mm band untouched for simplicity). Here the fit is acceptable. The rationale here is to say that the continuum is produced by the wings of the lines. If somehow the lines are broader than thought (in particular the 180 GHz line), then the continuum (typically going as ν^2) could have a bigger value than the one taken in the model. The width of atmospheric lines comes from pressure-broadening. The standard Pardo ATM model may be under-estimating the 2 mm continuum. In that case, the opacity correction that is done in the IDL pipeline remains correct.

We have tried to modify the oxygen band at 118 GHz or the water vapour line at 182 GHz but this cannot reproduce the data because the lines are near the edge of the bandpass.

3 Conclusions

We have made several attempts at reconciling the measured opacities with the ATM+bandpass model. Nothing works! except if we accept to modify the 2 mm continuum water vapour emissivity upward by a 1.55 factor. The 1 mm emissivity must be left untouched. This discussion does not address the opacity ratio observed between array 1 and 3 at 1 mm.

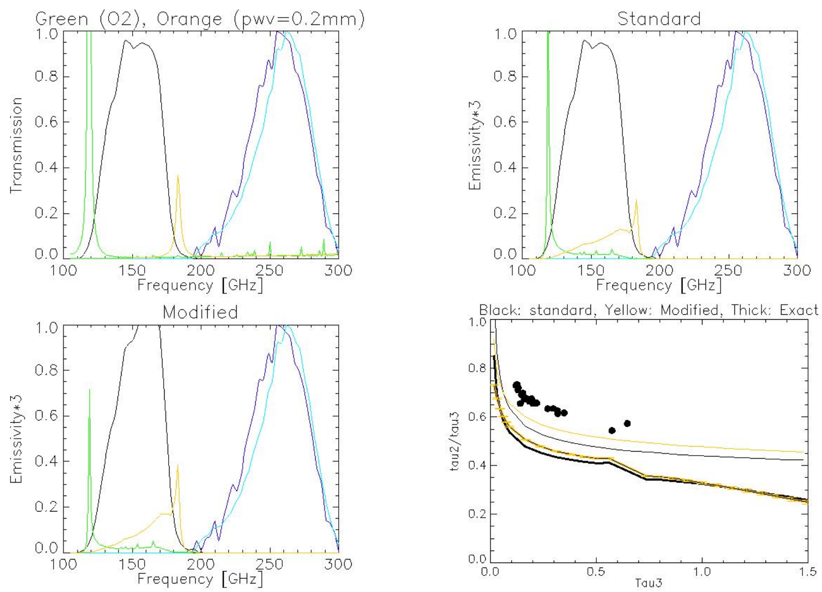

Figure 6: Modified modeling of the bandpasses. The 2mm bandpass is tilted to high-frequency by a centered power-law with an exponent of 2.

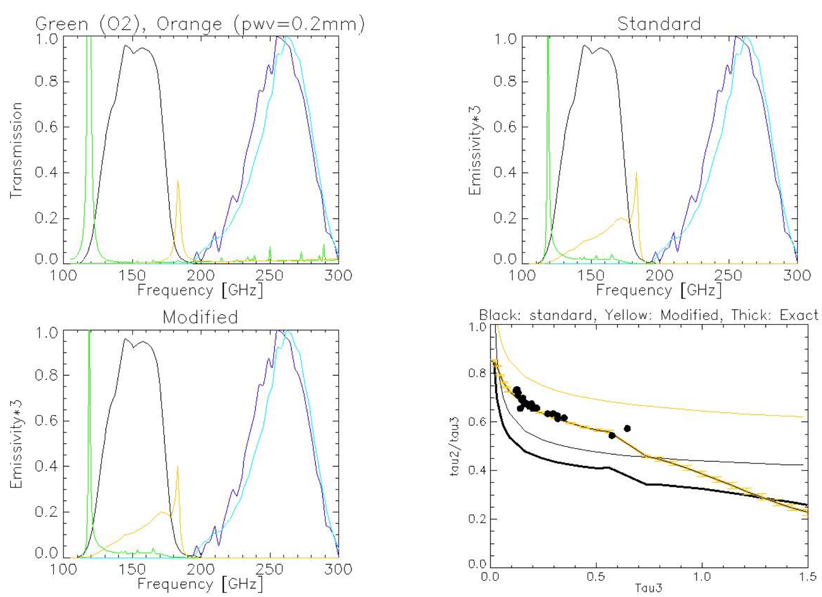

Figure 7: The water emissivity is changed by a factor 1.55 in the 2 mm band.