Analysis of Receiver Frequency Structure

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The Baseline

Assume that the power spectrum is measured on two sky positions, Ref and Sig. Let T_{sig} and T_{ref} represent the effective source temperatures at the respective positions. If we take the optimistic view that the receiver gain and noise temperature are completely stable over the measurement period, that is $G_{sig} = G_{ref}$ and $T_{rx,sig} = T_{rx,ref}$, then:

$$\frac{S_{sig} - S_{ref}}{S_{ref}} = \frac{T_{sig} - T_{ref}}{T_{ref} + T_{rx}(f)} \tag{1}$$

This equation shows that the quantity $(S_{sig} - S_{ref})/S_{ref}$ will only be flat with frequency if T_{rx} is flat, or $T_{sig} - T_{ref}$ is very small over most of the frequency range. The denominator of equation 1 is just $T_{sys}(f)$ during the reference scan, so multiplying by that value will retrieve the desired quantity $T_{sig} - T_{ref}$. The problem lies in accurate determination of $T_{sys}(f)$.

Y-factor

The most common engineering method of determining a receiver's noise temperature is to measure its output power with two known input source temperatures. The ratio of the two powers is termed the Y-factor. Since a spectrometer measures the spectral power versus frequency, we can use two astronomical sources to obtain $Y(f)$:

$$Y(f) = \frac{S_{sig}}{S_{ref}} = \frac{(T_{sig} + T_{rx,sig}(f))k_B G_s}{(T_{ref} + T_{rx,ref}(f))k_B G_r} \tag{2}$$

Again assuming receiver stability, and solving for T_{rx}, we obtain a familiar equation:

$$T_{rx}(f) = \frac{T_{sig} - Y(f)T_{ref}}{Y(f) - 1} \tag{3}$$

Experimental Data

Data taken both in the laboratory under idealized conditions, and on the GBT observing astronomical sources has been processed to study the possibility of measuring T_{sys} using the spectrometer in conjunction with spectrometry observations.

Q-band Laboratory Data

Measurements and analysis were made on a test arrangement consisting of a cooled LNA and mixer, IF filter, and IF amplifier taken from the Q-band receiver and placed in one of our test dewars. The LNA input port was connected to a cooled isolator and a cooled rectangular waveguide load. The load was thermally separated from the isolator with a length of stainless waveguide. A small heater and temperature sensor allowed the load temperature to be adjusted

The test dewar was located in the Equipment Room and the IF output (centered at 6GHz), and the spectrometer was configured for a 800 MHz bandwidth measurements of the spectrum. Figure 1 plots typical T_{rx} for this setup, calculated using the Y-factor approach. Figure 2 shows the effect on spectral baselines when the measured T_{rx} is used in equation 1.

X-band Astronomical Data

To see how the Y-factor measurement of $T_{rx}(f)$ behaves with a front-end operating on the GBT, astronomical data previously taken with the X-band receiver was analyzed. The first data set consisted of a sequence of on-off observations of NGC 7027. One observation was used to calculate T_{rx}, and that value used to analyze subsequent observations. Only one source was observed, but the data can provide an indication of the stability of the analysis. Examples from this dataset are shown in Figures 3 and 4.

The second X-band data set was a sequence of on-off observations of three sources. By coincidence, one of the sources was NGC 7027, and that source was used to determine T_{rx} applied to analysis of the other sources. The results are shown in Figures 5 and 6.

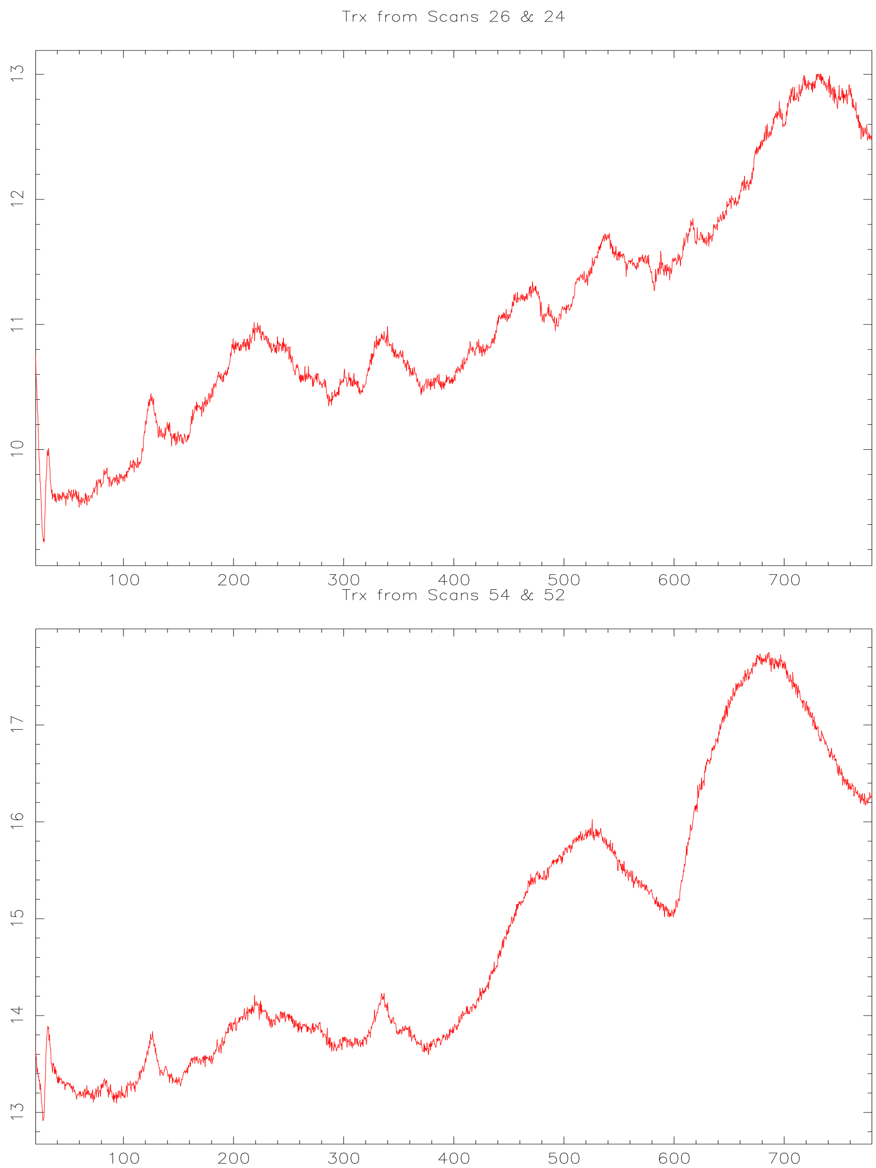

Figure 1: T_{rx} at 42 GHz (upper panel)and 43 GHz (lower panel), obtained from a test dewar containing a Q-band LNA and cooled mixer, calculated with equations 2 and 3. A heated waveguide termination was used to vary the LNA input load temperature.

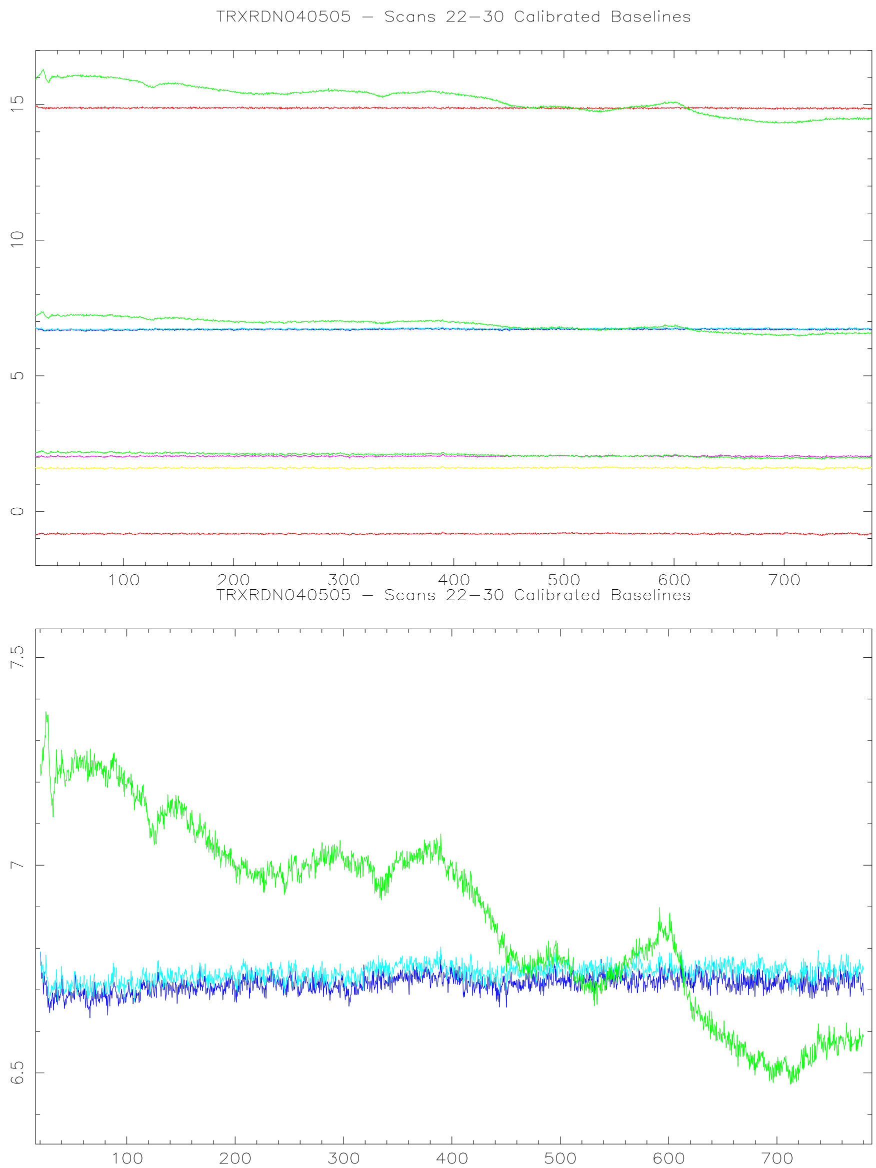

Figure 2: The upper plot shows the spectral baselines on the Q-band test dewar setup for several signal scans taken at various load temperatures. The green traces were calculated using a mean T_{rx} of 15.5K, and the other (flatter) traces used measured $T_{rx}(f)$. The lower panel zooms into the region around 7 K.

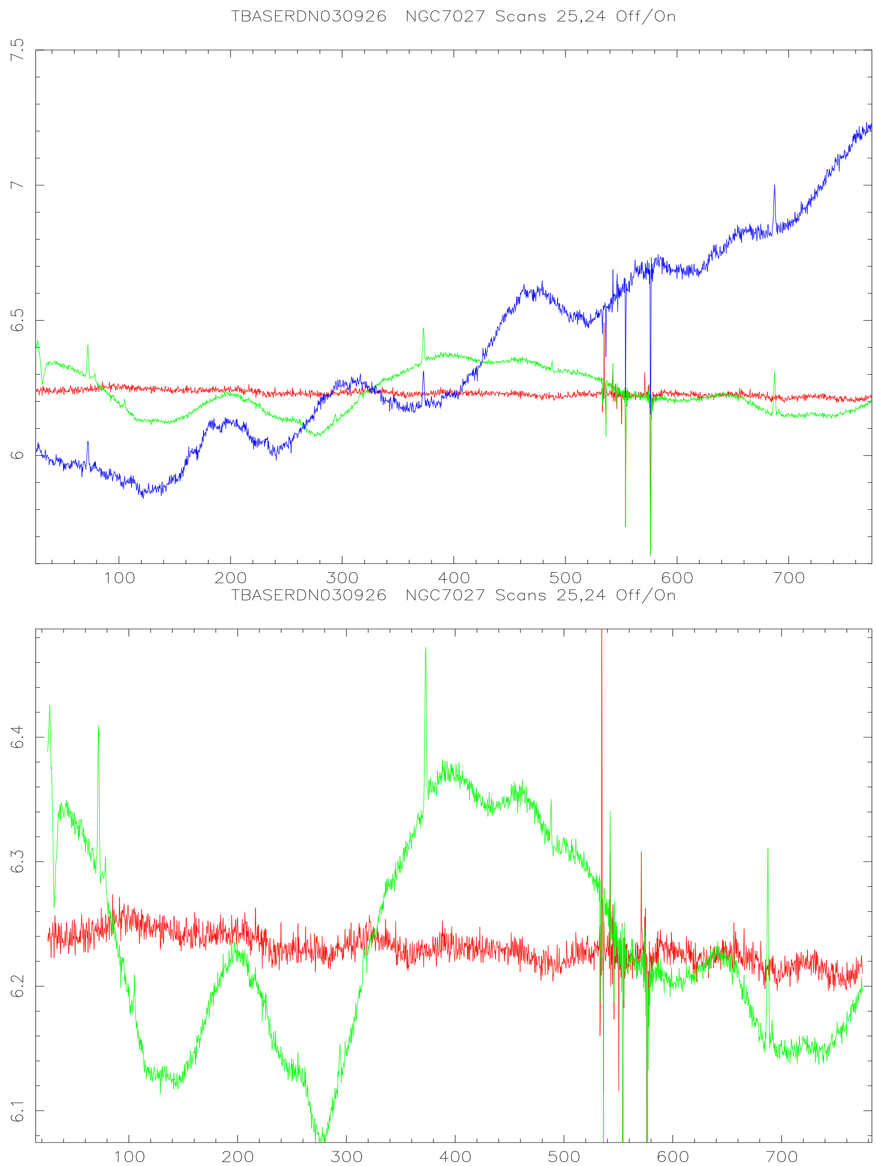

Figure 3: X-band spectral baselines calculated for TBASERDN030926 scan pair 24 and 25, ACS Bank A. The red trace was calculated using T_{rx} measured using scan pair 22 and 23 data as a Hot/Cold measurement. The green trace was calculated using a constant T_{sys}, and the blue trace used a T_{sys} derived from Cal On - Cal Off data in scan 25. The vertical scale corresponds to $T_{On} - T_{Off}$ in Kelvin. The lower panel shows the red and green traces in more detail. For these plots 400MHz on the horizontal axis corresponds to a sky frequency of 9000MHz, and sky frequency increases to the right. The data was from the RCP polarization.

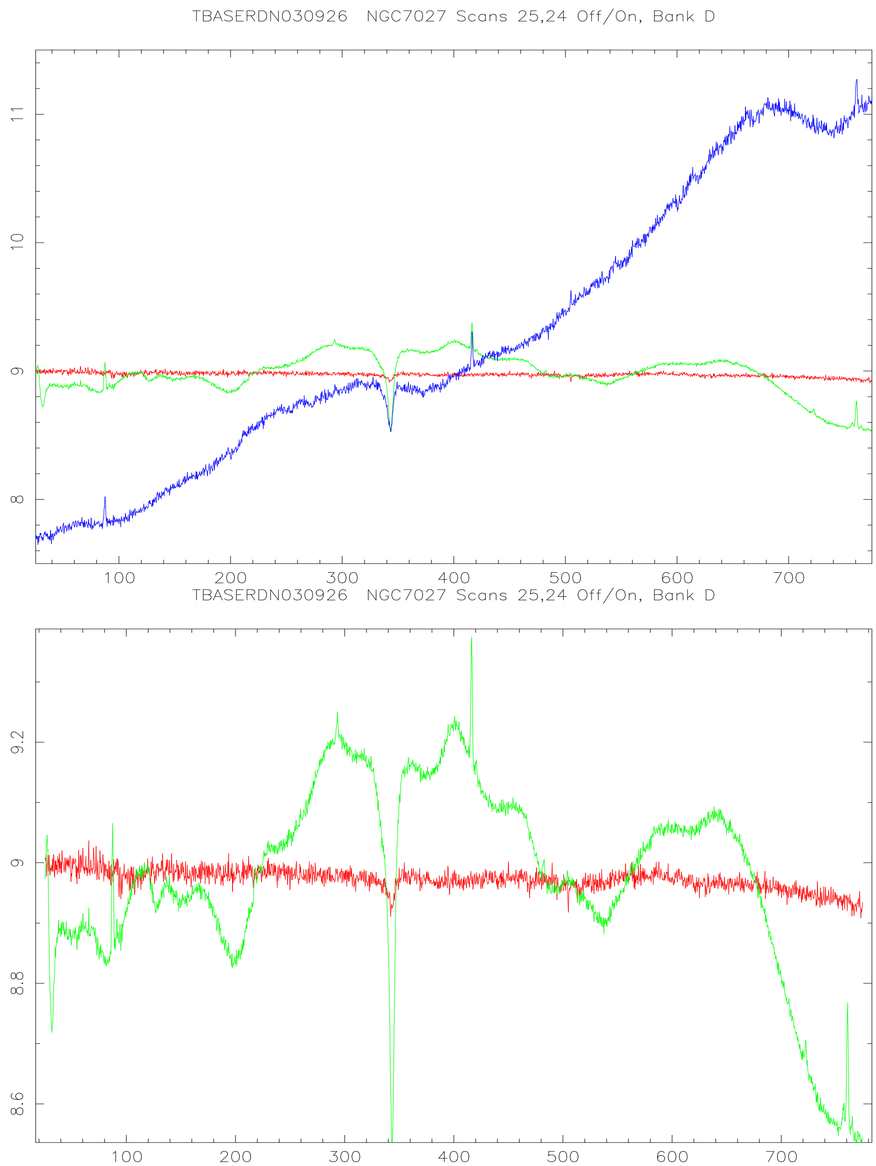

Figure 4: X-band spectral baselines calculated for TBASERDN030926 scan pair 24 and 25, ACS Bank D, calculated in three ways. The red trace was calculated using T_{rx} measured using scan pair 22 and 23 data as a Hot/Cold measurement. The green trace was calculated using a constant T_{sys}, and the blue trace used a T_{sys} derived from Cal On - Cal Off data in scan 25. The vertical scale corresponds to $T_{On} - T_{Off}$ in Kelvin. The lower panel shows the red and green traces in more detail. For these plots 400MHz on the horizontal axis corresponds to a sky frequency of 9600MHz, and sky frequency increases to the right. The data was from the RCP polarization.

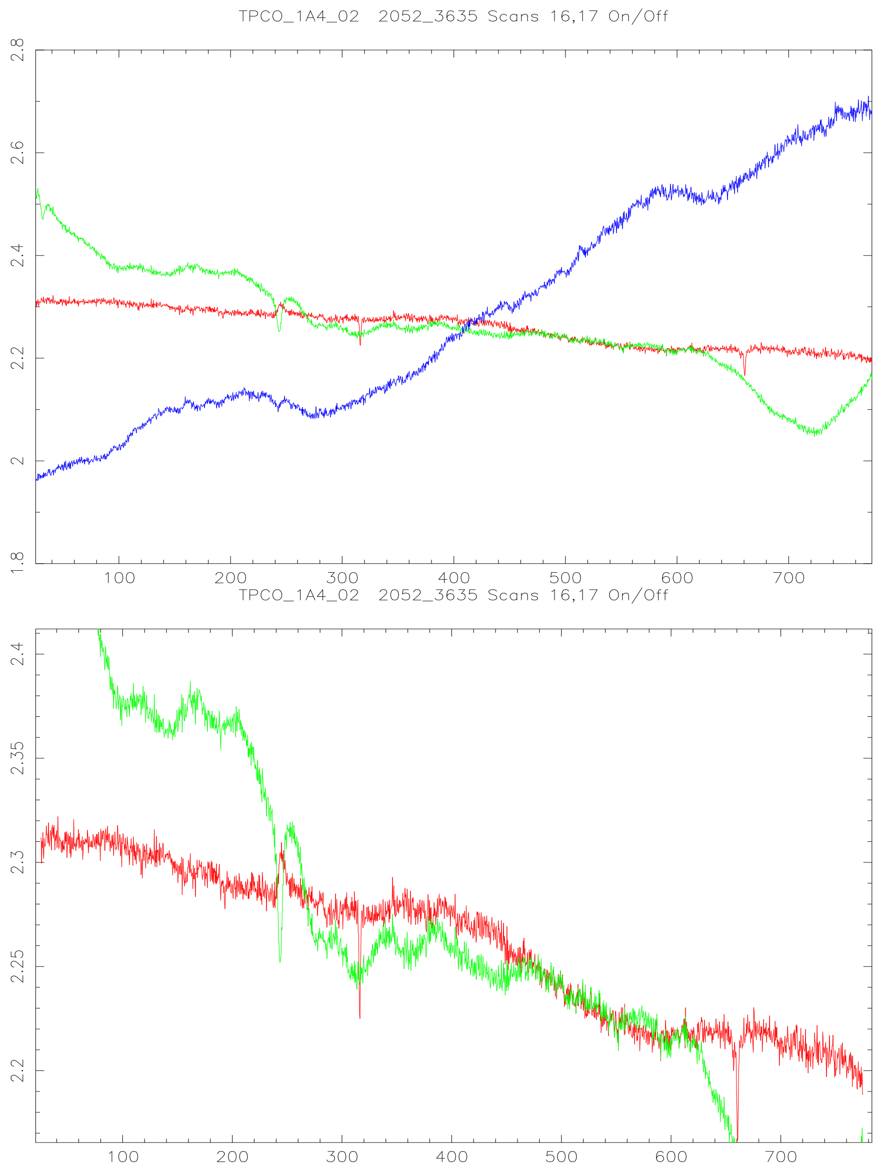

Figure 5: X-band spectral baselines for TPCO1A402 scan pair 16 and 17, on 2052−3635, calculated in three ways. The red trace was calculated using T_{rx} measured using scan pair 14 and 15, NGC 7027 data, as a Hot/Cold measurement. The green trace was calculated using a constant T_{sys}, and the blue trace used a T_{sys} derived from Cal On - Cal Off data in scan 17. The vertical scale corresponds to $T_{On} - T_{Off}$ in Kelvin. The lower panel shows the red and green traces in more detail. For these plots 400MHz on the horizontal axis corresponds to a sky frequency of 9900MHz, and sky frequency increases to the right. The data was from the RCP polarization.

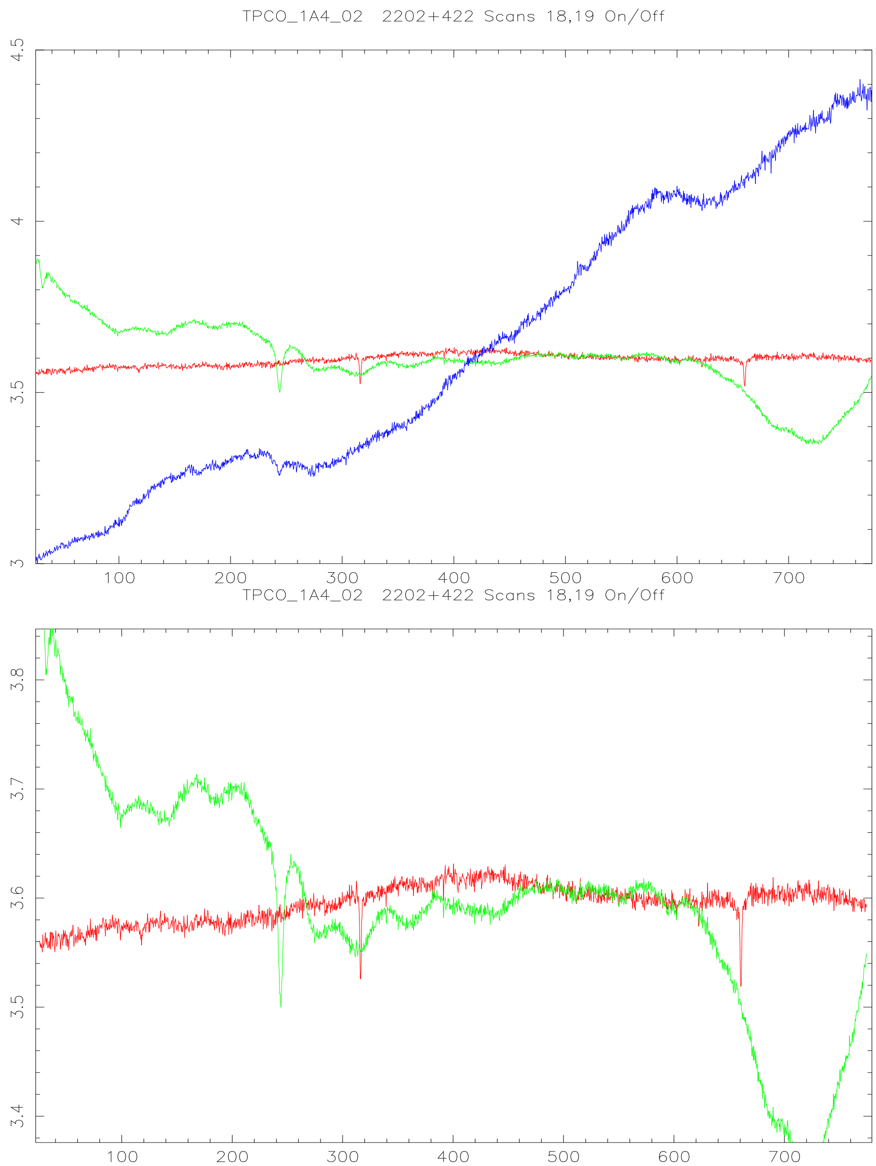

Figure 6: X-band spectral baselines for TPCO1A402 scan pair 18 and 19, on 2202+422, calculated in three ways. The red trace was calculated using T_{rx} measured using scan pair 14 and 15, NGC 7027 data, as a Hot/Cold measurement. The green trace was calculated using a constant T_{sys}, and the blue trace used a T_{sys} derived from Cal On - Cal Off data in scans 19. The vertical scale corresponds to $T_{On} - T_{Off}$ in Kelvin. The lower panel shows the red and green traces in more detail. For these plots 400MHz on the horizontal axis corresponds to a sky frequency of 9900MHz, and sky frequency increases to the right. The data was from the RCP polarization.