C-band Spectral Baseline Performance Projects TBASE_071025, TBASE_071030, & TBASE_071108

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Introduction

During early GBT commissioning observations it was evident that the spectral baselines were not as flat as expected given the clear aperture design of the telescope. In 2002-3 the spectral baseline structure was investigated and characterized using several different receivers, including C-band. One of the results of these studies was the detection of spectral baseline structures that scaled with source continuum and appeared to be isolated to the front-end. (Fisher et al. 2003, EDIR 312).

In 2006-7 changes in front-end design were explored using the C-band receiver to mitigate these spectral baseline structures.[1] There were two phases to this development: (1) adjustments in the dewar that consisted of cooling the OMT, shortening cable lengths, etc; and (2) re-designing the front-end components after the dewar, in particular the down-converter (Stennes 2007).

The first phase was completed by Fall 2006 and resulted in lower system temperatures by about $5 - 10$ K. Current system temperatures are now around 16 K. The second phase was completed by Fall 2007. The results of lab tests indicate relatively flat baselines and good stability.[2]. This memo discusses astronomical observations to investigate the spectral baselines of the new C-band receiver on the GBT.

Observations

Observations discussed here include data taken early on during the GBT commissioning. In particular we use data taken in 2002 from projects TBASE-JRF021230 and TBASEDSB021121. Since then there have been many improvements to various components in the IF chain (e.g., new external optical fiber modulators to reduce the 2.4 MHz ripple; improvements in the linearity of the components in the IF rack; improvements in the stability and isolation of the

[1] See http://wiki.gb.nrao.edu/bin/view/Electronics/CbandReceiver.
[2] see http://wiki.gb.nrao.edu/bin/view/Electronics/TCRX06OCT07

Table 1: Setup 1

BACKEND	BANK	PORT	FEED	POL	SIDEBAND	SKY FREQ	BANDWIDTH
Spectrometer	A	1	1	X	L	4.40024781e+09	800000000
Spectrometer	A	2	1	Y	L	4.40024781e+09	800000000
Spectrometer	B	3	1	X	L	5.00024781e+09	800000000
Spectrometer	B	4	1	Y	L	5.00024781e+09	800000000
Spectrometer	C	5	1	X	L	5.00024781e+09	800000000
Spectrometer	C	6	1	Y	L	5.00024781e+09	800000000
Spectrometer	D	7	1	X	L	5.55012403e+09	699752128
Spectrometer	D	8	1	Y	L	5.55012403e+09	699752128

Table 2: Setup 2

BACKEND	BANK	PORT	FEED	POL	SIDEBAND	SKY FREQ	BANDWIDTH
Spectrometer	A	1	1	X	L	5.00023706e+09	800000000
Spectrometer	A	2	1	Y	L	5.00023706e+09	800000000
Spectrometer	B	3	1	X	L	5.00023706e+09	800000000
Spectrometer	B	4	1	Y	L	5.00023706e+09	800000000
Spectrometer	C	5	1	X	L	5.00023706e+09	800000000
Spectrometer	C	6	1	Y	L	5.00023706e+09	800000000
Spectrometer	D	7	1	X	L	5.00023706e+09	800000000
Spectrometer	D	8	1	Y	L	5.00023706e+09	800000000

converter modules; etc.). We were unable to take any good C-band data prior to the changes make in 2007. Therefore, we do not have the data to make very good comparisons.

Observations made to characterize the recent enhancements to the C-band receiver were taken in Fall 2007 in projects TBASE_071025, TBASE_071030, & TBASE_071108. Most of the data were taken in two spectrometer configurations show in Table 1 and 2. In both cases the 1.6 GHz sampler are used for a bandwidth of 800 MHz. In Table 1 the first three banks cover the entire C-band receiver frequency range; two spectral windows are tuned to 5000 MHz at the center. In Table 2 all banks are tuned to the center band. Therefore, the same rest frequency and IF signal is used before the optical fibers.

Results

Figure 1 shows the source continuum structure across the C-band receiver for the old and new designs. The detailed structure is different but otherwise there are no major differences. Figures 2 and 3 show source continuum spectra near the center of the old and new C-band receiver for three sources with varying intensities. The spectra are normalized in Figure 3 to show that the spectral baseline structure scales with source continuum. In the data taken in 2002 there was an intermittent 50 MHz ripple that probably resides in the converter module. The converter modules have since been modified to reduce such baseline structure.

Figure 4 shows waterfall plots of consecutive OffOn pairs (2 min ON/2 min OFF integrations) on cold sky. The spectra are relatively flat but vary slightly in continuum level with time. Figure 5 shows that the noise integrates down about as expected after about 1 hour. The final averaged spectrum does have some large-scale structure. Figure 6 shows OffOn spectra on cold sky during poor weather conditions (rain). The spectra are not only offset from zero, as would be expected under these conditions, but the larger the difference in total power between the OFF and ON scans the larger the spectral baseline structure.

Figure 7 shows OffOn source continuum spectra for the second configuration where all four spectral windows are tuned to the center of the band. The X-pol channel shows significant differences between different Spectrometer banks and this structure is repeatable. The continuum source, 3C147, is 7.66 Jy (15.3 K) at C-band. We balance the spectrometer ON source and therefore the samplers are set to ~ 3 dB lower than normal (a factor of 0.7) during the OFF scan. Fisher et al. (2003) explored spectral baseline structure with varying input power levels into the Spectrometer. They discovered that lower power levels produced larger amplitude variations but it did not appear to alter the frequency structure. Comparison of spectra with different continuum intensities scaled to the same level shows that most of this structure scales with source continuum (Figure 8).

In Figures 9 and 10 the location of the source continuum structure is investigated by switching cables at different locations in the signal path and changing local oscillator settings, respectively. In Figure 9 cables are swapped at the input to the converter modules and the input to the Spectrometer. The structure does not significantly change. The results are similar in Figure 10, although some structure does appear to move when the LO2 value is shifted. Figures 11 and 12 are OffOn source continuum spectra using the low speed samplers with 50 MHz bandwidth at 9-level and 3-level sampling, respectively. The 50 MHz bands were centered at 5140 MHz where there exists a lot of structure in the 800 MHz bandwidth spectra. The 50 MHz bandwidth spectra are relatively flat with only a few percent variation in continuum level. The continuum level for the low speed samplers at 50 MHz bandwidth is $\sim 0.83\,T_{\rm sys}$ for both 3 and 9-level sampling, while the continuum level for the high speed samplers at 800 MHz bandwidth ranges from $\sim 0.90 - 1.1\,T_{\rm sys}$. For comparison, the DCR Peak scans measured $T_{\rm src} = 15$ K with $T_{\rm sys} = 17$ K, so the continuum source intensity measured with the DCR was $\sim 0.88\,T_{\rm sys}$.

Conclusions

The C-band receiver was modified over the last year to improve the spectral baseline structure and stability. Cooling the OMT has resulted in lower system temperatures where $T_{\rm sys} = 17$ K on cold sky. OffOn spectra on cold sky produce relatively flat baselines over 800 MHz bandwidths with an rms noise that integrates down as expected to within a factor of 1.2. Significant spectral baseline structure exists for OffOn spectra on strong continuum sources. Most of this structure appears to reside in the Spectrometer.

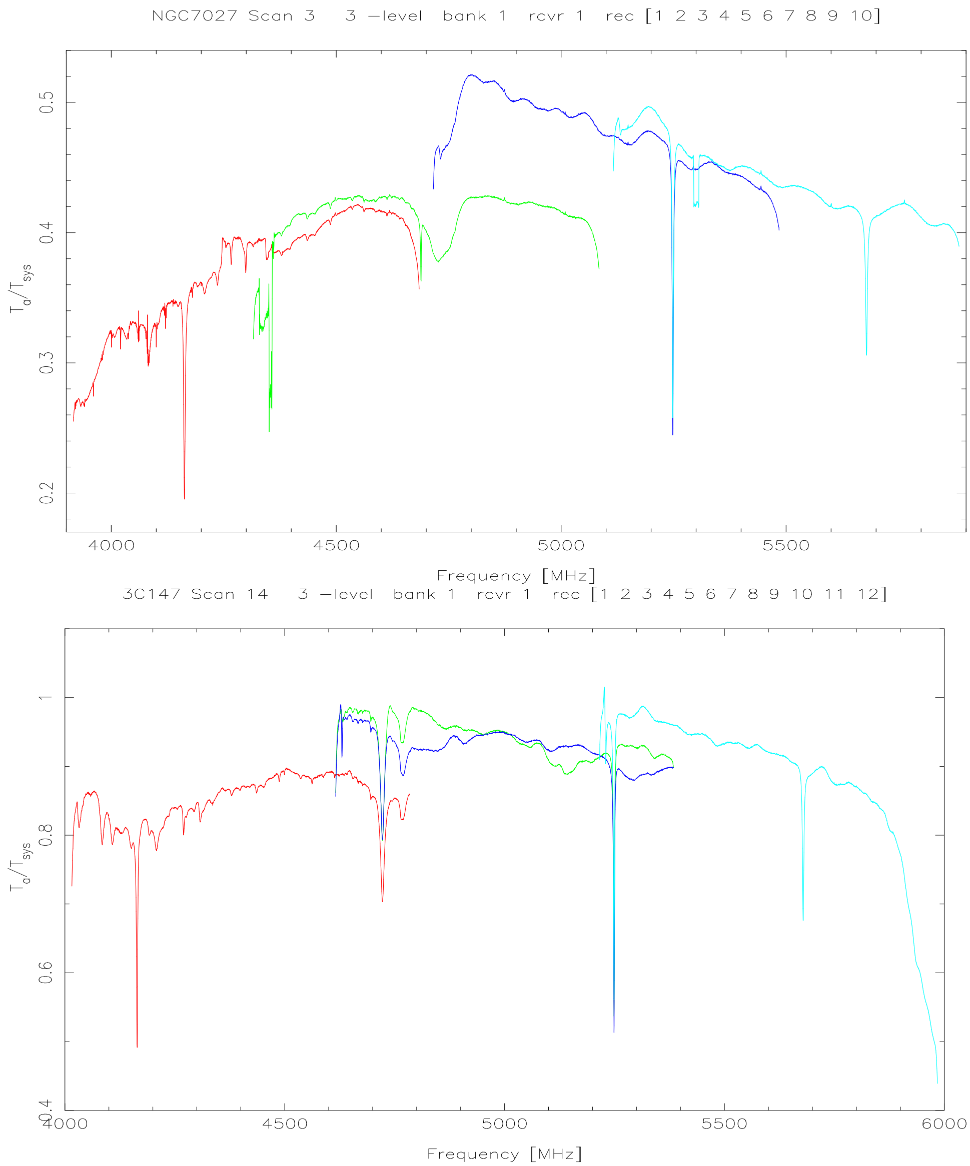

Figure 1: Source continuum structure across the C-band receiver for project TBASEJRF021230 using NGC7027 in 2002 (top) and TBASE_071030 using 3C147 in 2007 (bottom).

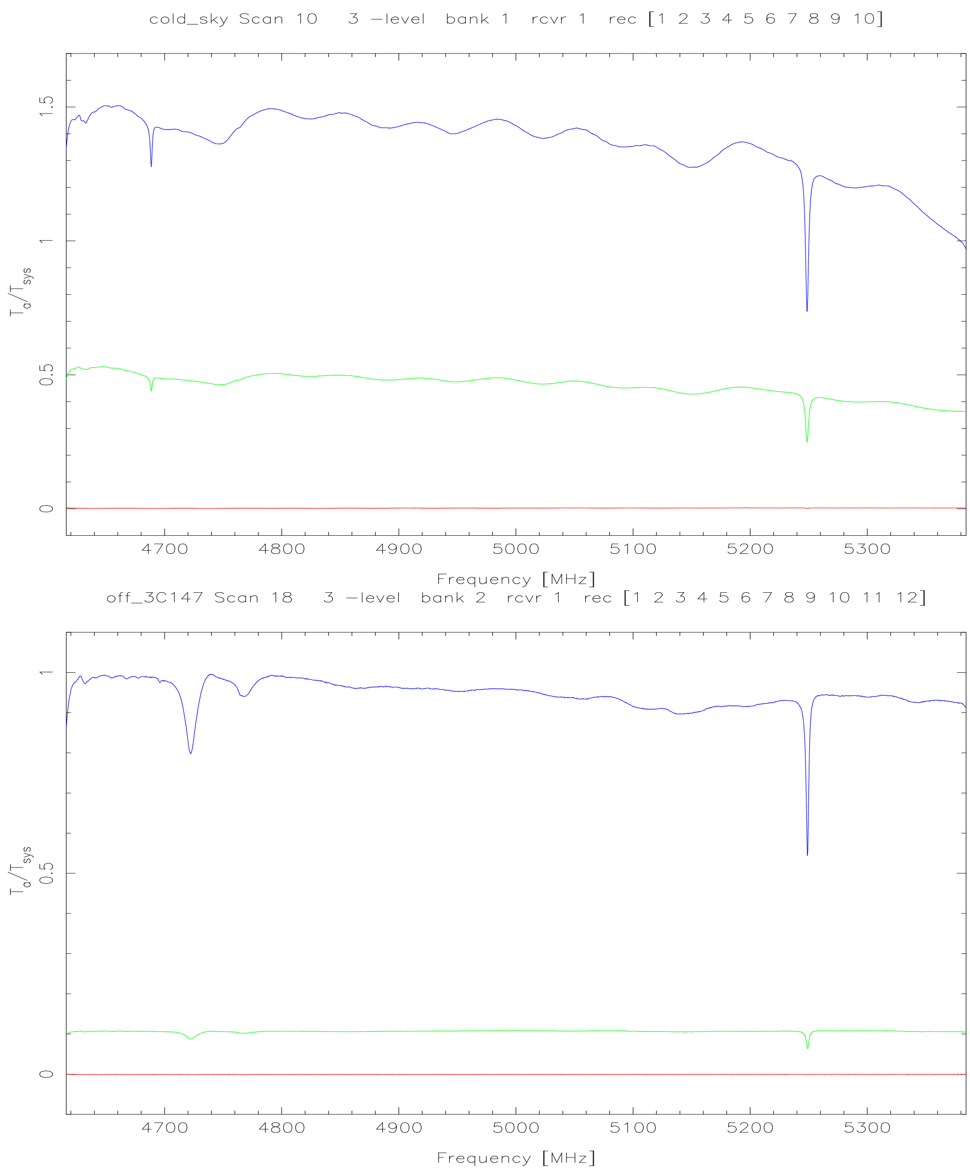

Figure 2: OffOn spectra for different continuum source levels. Top panel: project TBASEDSB021121 using cold sky (red), 0137+3309 (green), and 0319+4130 (blue). Bottom panel: project TBASE_071030 using cold sky (red), 0303+4716 (green), and 3C147 (blue).

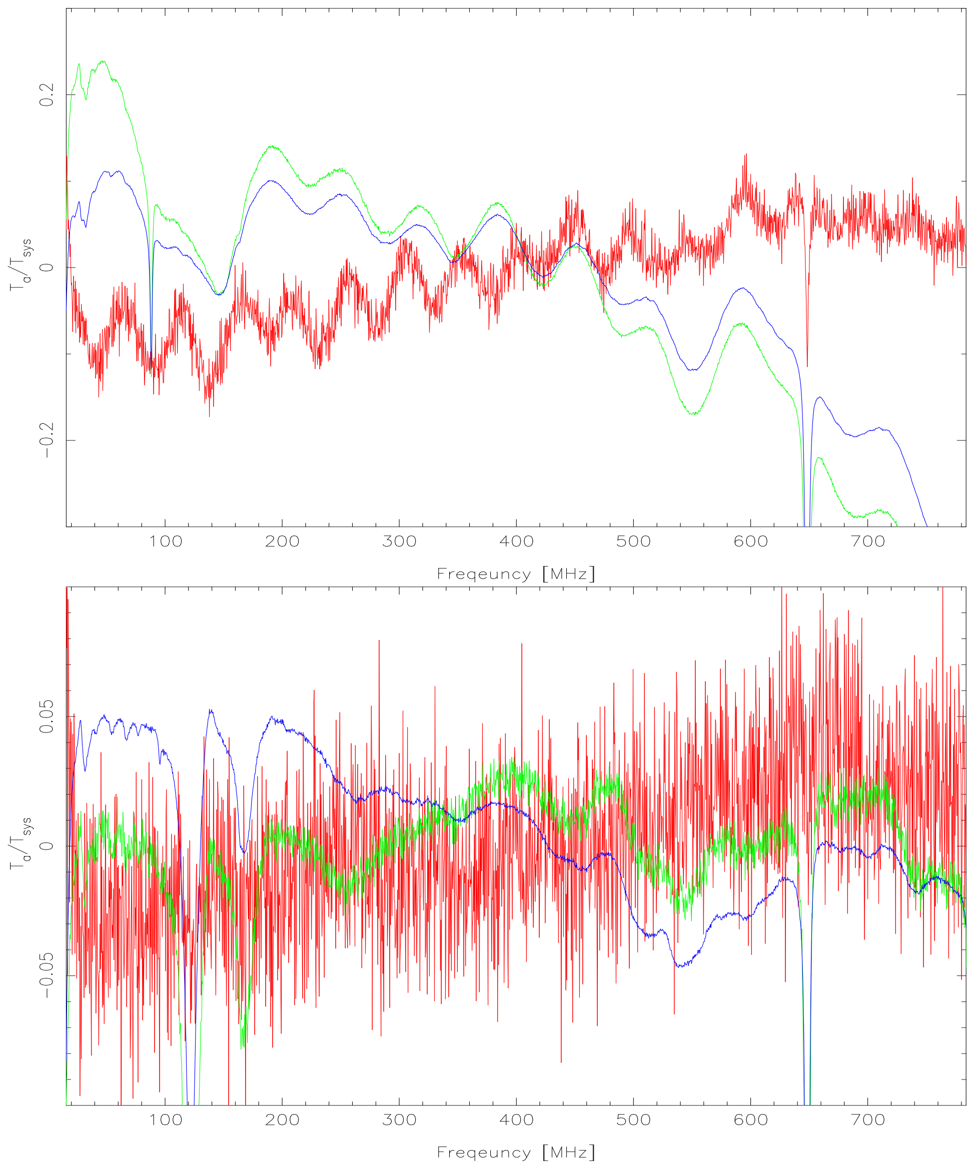

Figure 3: Same as Figure 2 except the spectra have been normalized by subracting a median DC offset from each spectrum. Also, the spectra have been scaled by 100 (red), 4 (green), and 1 (blue) for the top panel and by 100 (red), 15 (green), and 1 (blue) for the bottom panel.

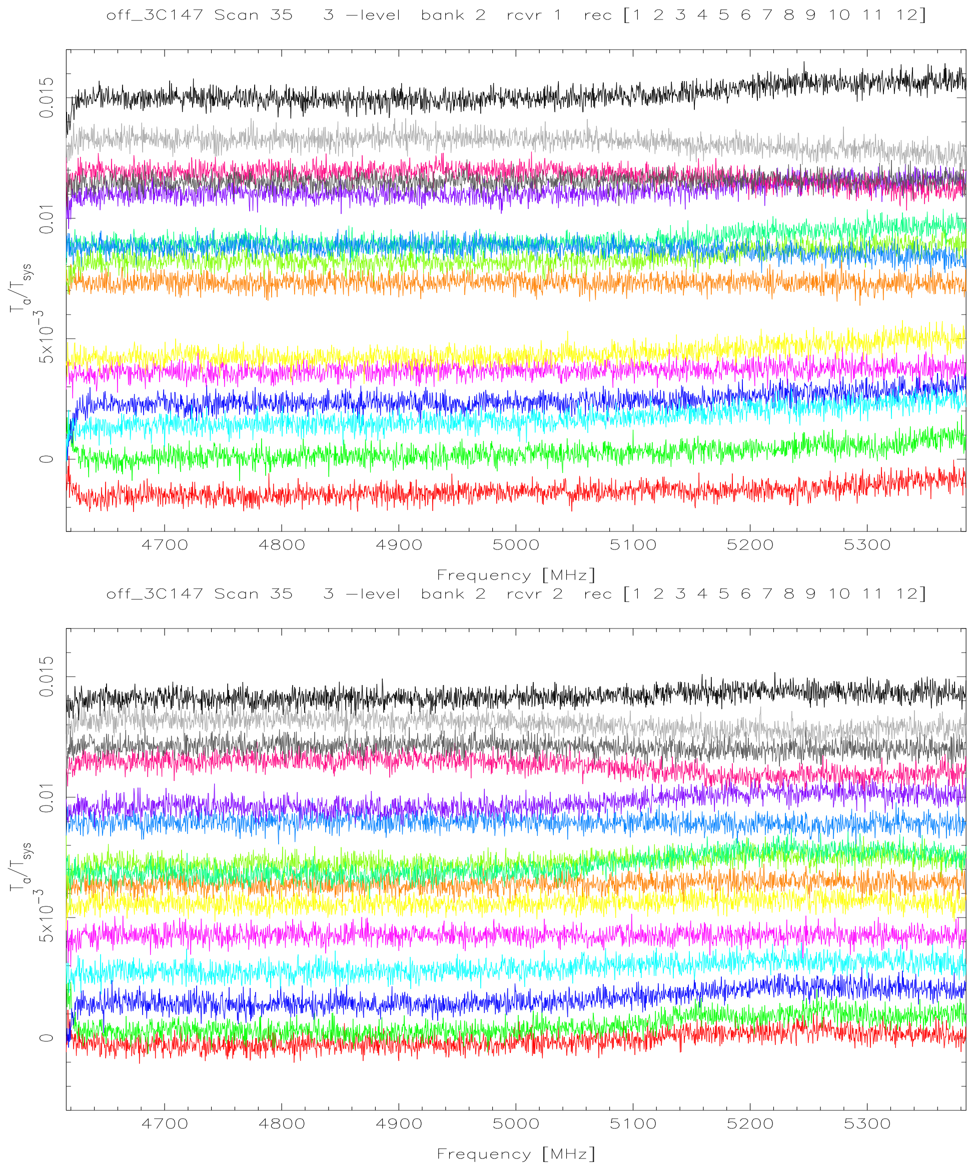

Figure 4: Waterfall plot of OffOn spectra on cold sky for project TBASE_071030 for the X-pol channel (top) and the Y-pol channel (bottom). Each scan consists of 12, 10 second integatrations for a total time of 2 minutes. The plots are offset by 0.001 but a DC value has not been removed from each spectrum.

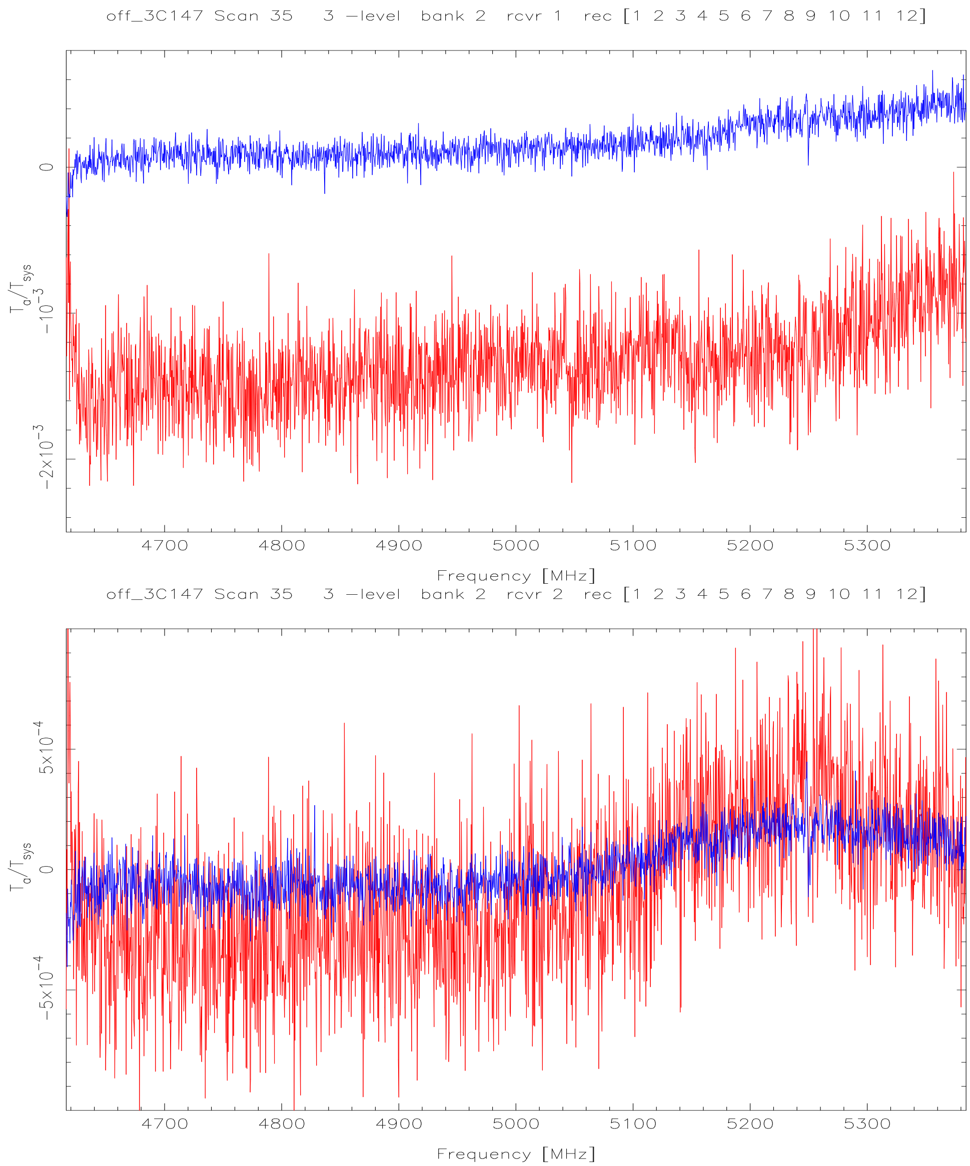

Figure 5: OffOn spectra on cold sky for project TBASE_071030 for X-pol channel (top) and Y-pol channel (bottom). The red curves with higher noise are one single OffOn pair (scans 34 and 35) with a 2 minute integration time. The blue curves are an average of 15 pairs. The noise integrates down to within a factor of 1.19 of theoretical over the entire band.

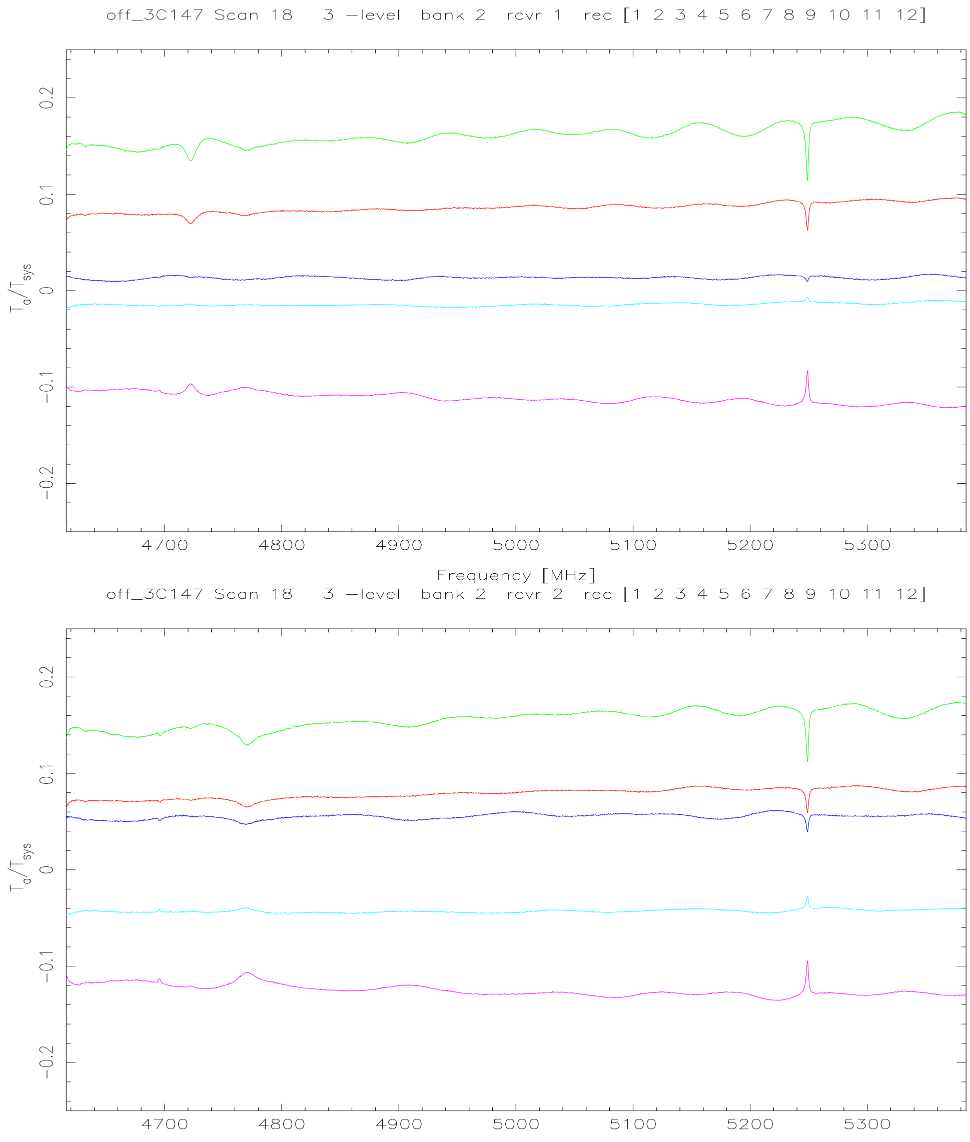

Figure 6: OffOn spectra on cold sky for project TBASE_071025 during poor weather conditions for the X-pol channel (top) and the Y-pol channel (bottom). No offset or DC value has been applied. The offsets in the data are due to varying weather conditions between the Off and On scans.

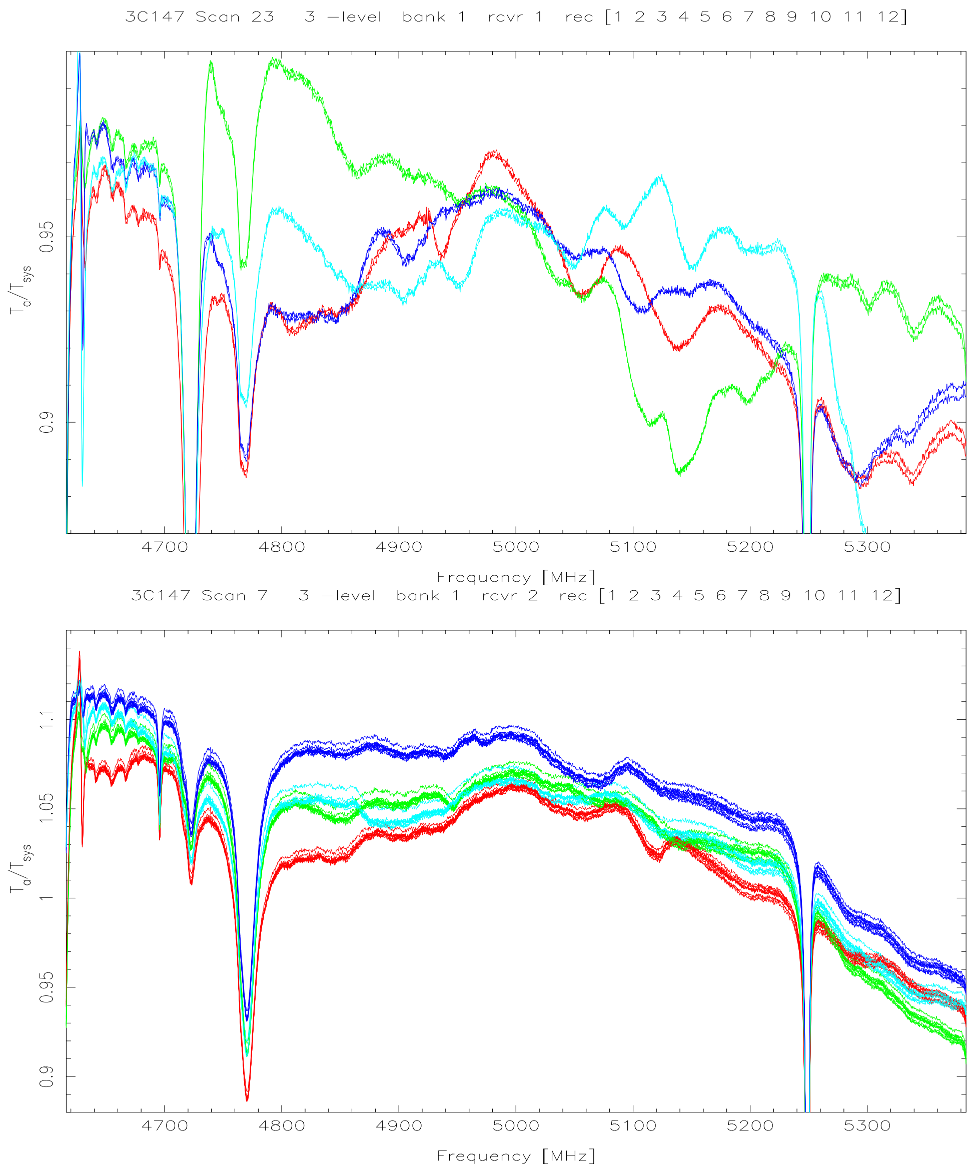

Figure 7: OffOn spectra on 3C147 for project TBASE_071108 for the X-pol channel (top) and the Y-pol channel (bottom). The system was configured such that all spectrometer samplers were looking at the same front-end and optical fiber signal path but differnt IF paths after the optical fiber. The colors correspond to these different paths where bank A is red, bank B is green, bank C is blue, and bank D is cyan. Ten OffOn Pairs are plotted for each bank.

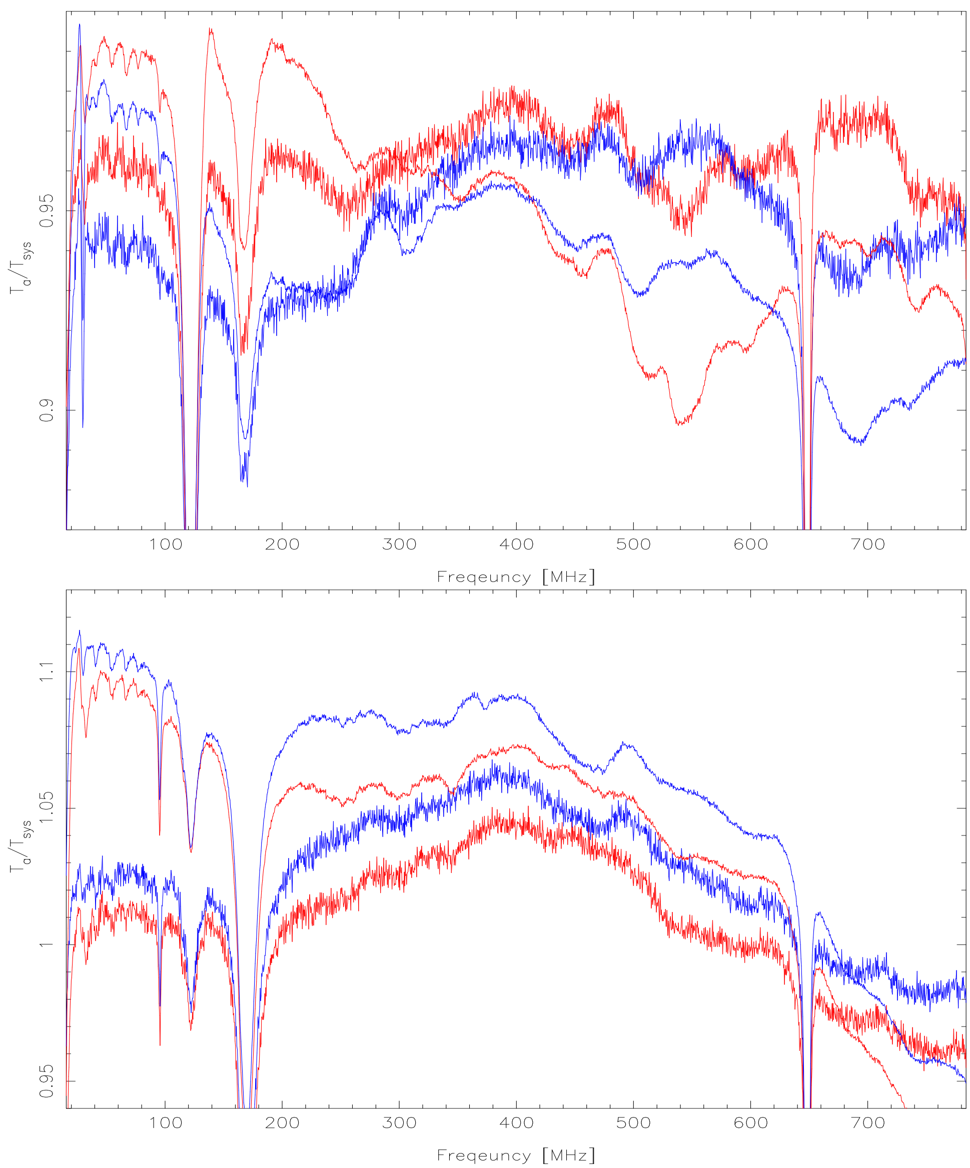

Figure 8: OffOn spectra for two continuum sources for the X-pol channel (top) and the Y-pol channel (bottom) for project TBASE_071030. The spectra with more noise are 0319+4130 scaled by a factor of 9.0, while the other spectra are 3C147. The colors correspond to different banks of the Spectrometer that have the same front-end signal where bank 2 is red and bank 3 is blue.

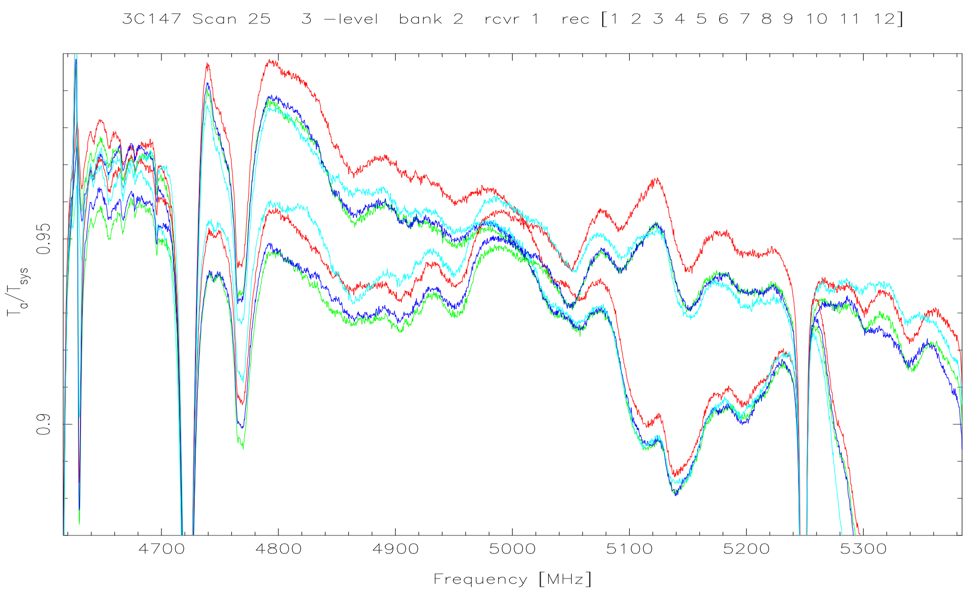

Figure 9: OffOn spectra on 3C147 for project TBASE_071108 for the X-pol channel. The system was configured such that all spectrometer samplers were looking at the same front-end and optical fiber signal path but diffent IF paths after the optical fiber. The colors correspond to different OffOn pairs where red is the nominal case with the IF target level set to 1V; green has the IF target level set to 3V; blue has the IF target level set to 3V and the cables input into CM2 and CM4 are swapped; cyan has the IF target level set to 3V and the cables input into ACS-J3 and ACS-J7 are swapped. The two spectra associated with each color correspond to Banks B (nominally CM2, ACS-J3) and D (nominally CM4, ACS-J7).

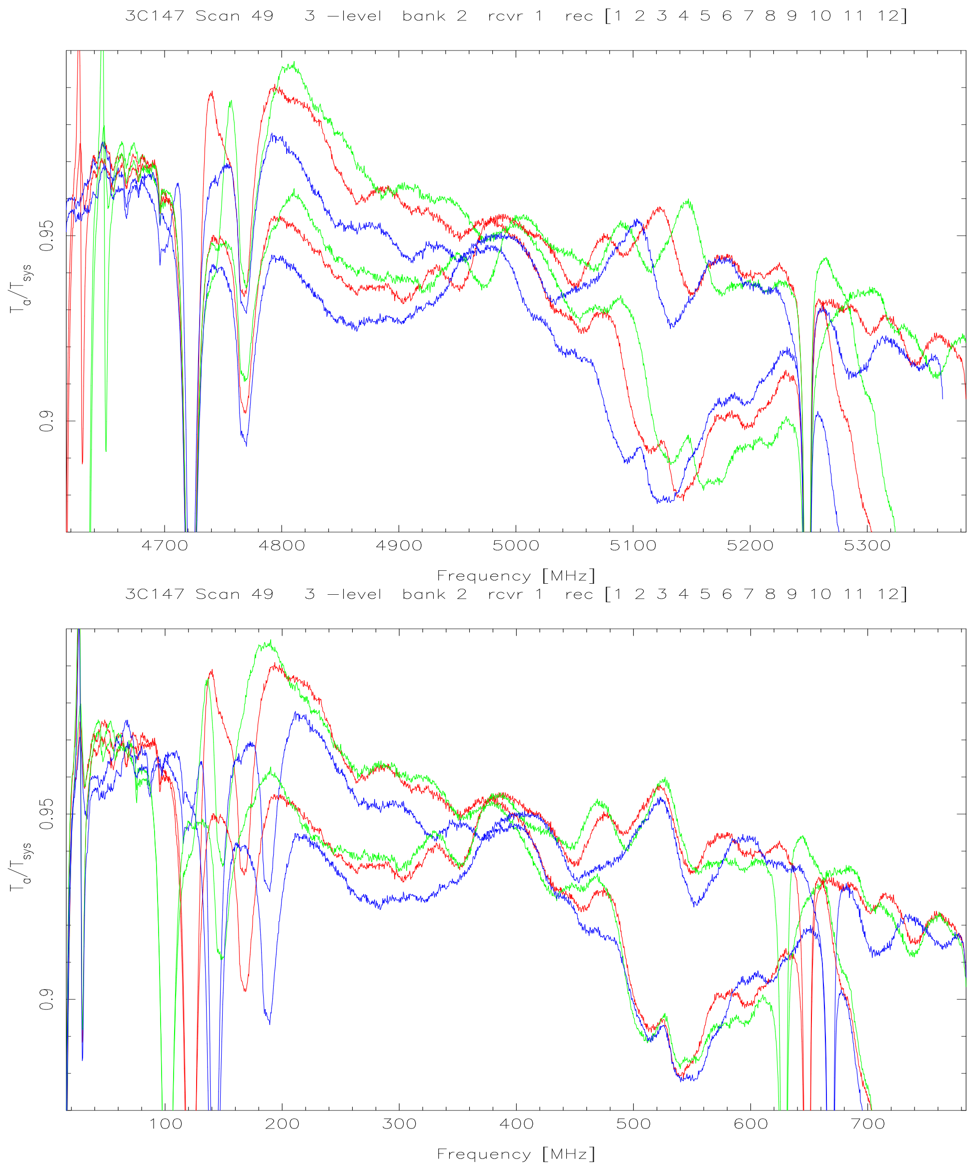

Figure 10: OffOn spectra on 3C147 for project TBASE_071108 for the X-pol channel. The system was configured such that all spectrometer samplers were looking at the same front-end and optical fiber signal path but diffent IF paths after the optical fiber. The colors correspond to different OffOn pairs where red is the nominal case; green has the LO1 shifted by 20 MHz; and blue has the LO2 shifted by 20 MHz. The two spectra associated with each color correspond to Banks B (nominally CM2, ACS-J3) and D (nominally CM4, ACS-J7). Top Panel: sky frequency is displayed where spectral features introduced ahead of the mixed will line up. Bottom Panel: baseband frequency is displayed where spectral features introduced behind the mixer will line up.

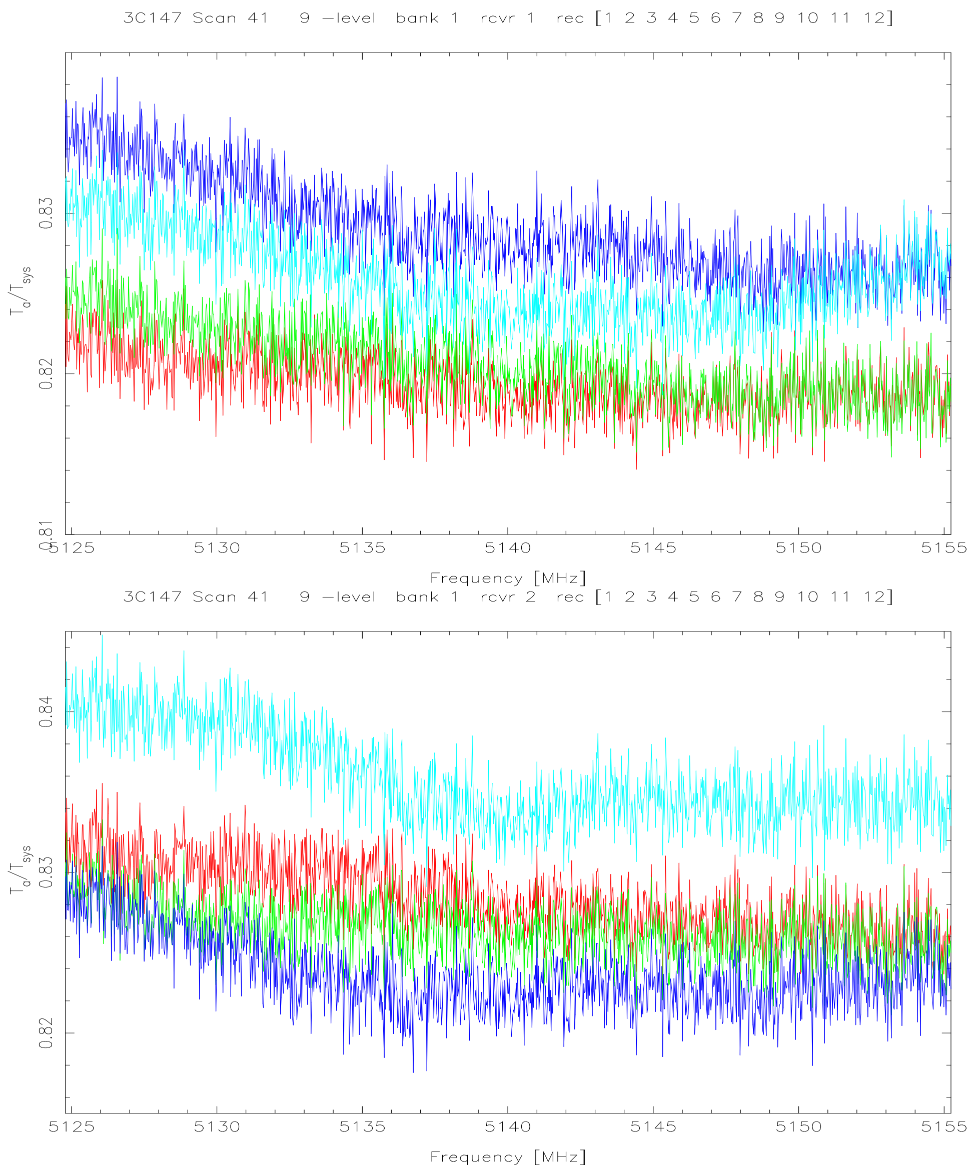

Figure 11: OffOn spectra on 3C147 for project TBASE_071108 for the X-pol channel (top) and the Y-pol channel (bottom) using the 50 MHz, 9-level sampler mode of the Spectrometer. The diffenent colors correspond to different banks of the Spectrometer which are all tuned to 5140 MHz. The data have been smoothed by truncating the ACF function by a factor of 2.

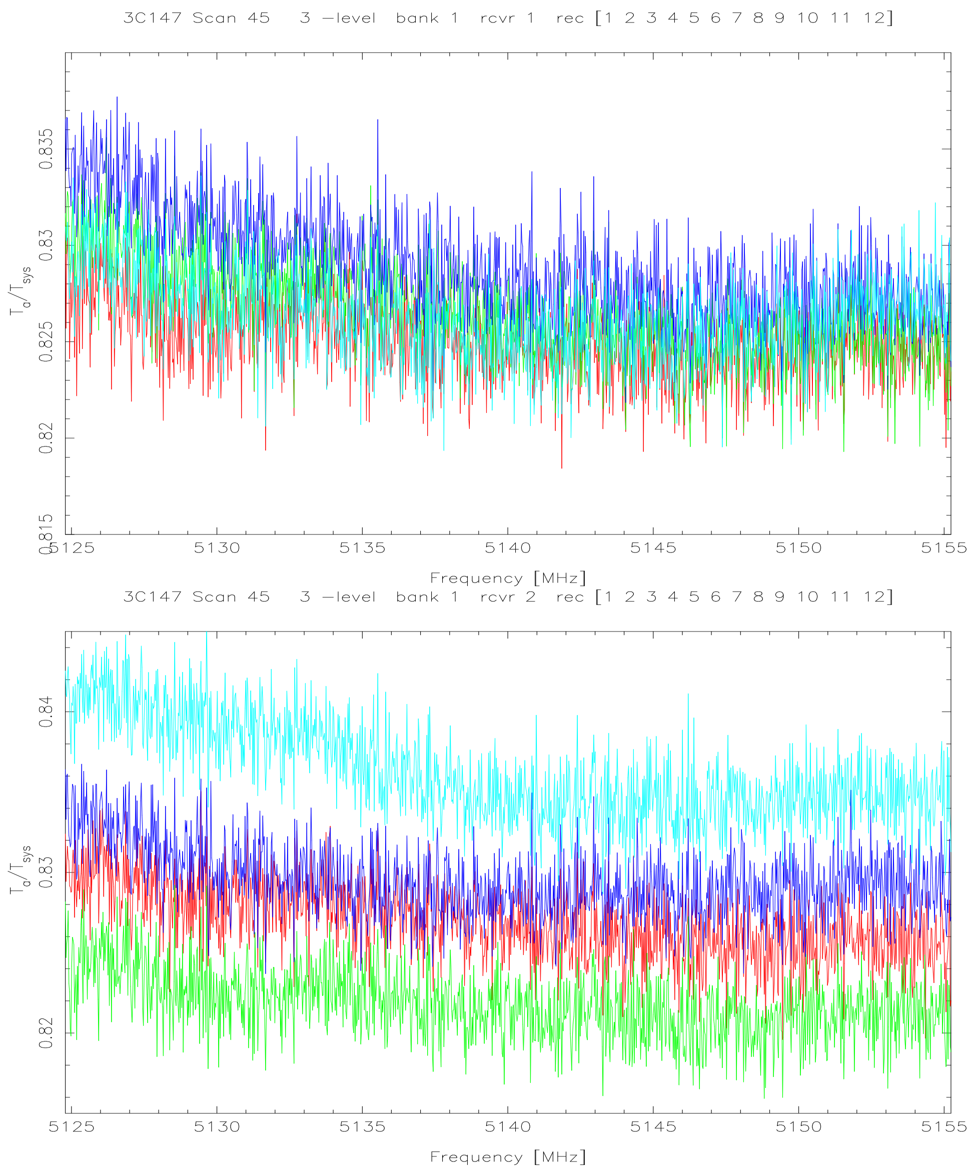

Figure 12: OffOn spectra on 3C147 for project TBASE_071108 for the X-pol channel (top) and the Y-pol channel (bottom) using the 50 MHz, 3-level sampler mode of the Spectrometer. The diffenent colors correspond to different banks of the Spectrometer which are all tuned to 5140 MHz. The data have been smoothed by truncating the ACF function by a factor of 8.