Comparison of GBT Back End Total Intensity Measurements

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Abstract

This document describes total power measurements with the Green Bank Telescope towards reference radio sources, using the Digital Continuum Receiver (DCR), Spectral Processor (SP) and Autocorrelation Spectrometer (ACS) "Back Ends". The observations were made centered on sky frequency 1408 MHz, with 20 MHz wide band pass filter. In the configuration tested, the SP and DCR measurements agree to better than 13 % for observations of NGC7027 and agree to better than 2 % for 3C48. The ACS yielded values that are 6 to 12 % higher than those for the SP.

Some suggests are given for the cause of the difference in apparent source brightnesses for the different backends.

GBT Setup

The test observations were made on 2001 November 28 using the 1-2 GHz receiver. The observations were made to check the 1-2 GHz receiver noise diode calibration over the entire 1-2 GHz range. Several reference sources from the Ott *et al.*(1994, *A&A*, **284**:331) list were observed with the DCR and SP. The noise diode calibration data will be described elsewhere.

The two sources, NGC7027 and 3C48, were observed using all three Back Ends and these measurements are presented here. Table 1 lists the Ott *et al.* (1994) flux densities at 1408 MHz for these sources. GBT Memo 155, by Norrod, R and Srikanth, S. (1996), indicates the predicted GBT efficiency at 1.4 GHz is 71.8 %. For this efficiency and a 100m diameter dish, the conversion factor from Jy to K is 2.04 K/Jy. The corresponding Kelvin values for NGC7027 and 3C48 are included in table 1.

The observations with the different back ends were not made simultaneously, but were performed within a few minutes, so there was little change in weather or source elevation.

Mike Stennes reports that the 1408 MHz noise diode effective temperatures were 1.88 K for X linear polarization and 1.86 K for Y linear polarization. For these tests, the value adopted was 1.86 K for both polarizations (resulting in a 1% underestimate for the X linear polarization intensities).

All data were recorded in the standard GBT Monitor and Control FITS files. The data are archived in directory `/home/gbtdata/tigerTeam_09`.

Source Name	Flux Density (Jy)	Obs Az (d)	Obs El (d)	Brightness Temp (K predicted)
3C48	16.27±0.08	-71.0	66.7	33.24 ±0.16
NGC7027	1.37±0.01	153.3	84.5	2.80 ±0.02

Table 1: Flux densities reported by Ott *et al.*1994 for bright calibration sources observed. The predicted values are based on estimates in GBT Memo 155

DCR Configuration

The source intensities were measured with the DCR using the "GO" peak procedure, where the source as scanned along lines of constant RA and Declination over an angular interval of 1 degree, sampling the source intensity 160 times in this interval. The DCR data were sampled at the IF Rack sampler, which is located at the GBT in the receiver room.

The DCR data were reduced using `aips++`. One measurement of the source intensity was produced from a Gaussian fit to four scans of the source. The value in table 2 is the median of the four Gaussian fits. Figure 1 shows four consecutive scans on source 3C48. All of the DCR data used were free of significant baseline jumps and have appearance similar to the scans shown in figure 1. The DCR was set up to control the switching signals to the receiver.

Since the DCR temperature values are greater than the predicted values temperature values, the rate of sampling the sky brightness was probably sufficient. Possibly the GBT efficiency is greater than the value predicted, or the noise diode values used are higher than the actual temperatures.

SP Configuration

The Spectral Processor (SP) was configured for the dual polarization, 20 MHz bandwidth 1024 channel mode. The SP controlled the switching signals. The observations were performed using the "GO" OffOn procedure. The OFF source position was 1 degree east (in right ascension) of the ON source position.

Both the SP and ACS are located in the GBT equipment room, about 1 km from the GBT. The IF signals are transmitted via fiber optical modems to these back ends.

The data were calibrated by determining the system temperature from the Off source observation and then calibrating the source intensity from the ratio of (On Source - Off Source)/(Off Source). Figures 2-5 show the spectral band of the observations. The SP values in table 2 are from processing using the `spectrometer` program. The `spectrometer` and `aips++` intensity outputs agree for the X-linear polarization, but the `aips++` output for the Y-linear polarization is too low.

SP balancing between pairs of scans was turned off so that the (On - Off)/(Off Source) calculation could be performed.

Source Name	Backend Name	Scans (#)	T (X Pol) (K)	T (Y Pol) (K)	ΔT X (%)	ΔT Y (%)
NGC7027	DCR	78-81	3.03 ±0.05	2.94 ±0.04	0	0
NGC7027	SP	86-87	3.45 ±0.05	3.31 ±0.02	13	13
NGC7027	SP	90-91	3.35 ±0.04	3.28 ±0.04	10	12
NGC7027	ACS	98-99	3.72 ±0.03	3.54 ±0.03	22	20
NGC7027	ACS	100-101	3.70 ±0.04	3.48 ±0.03	22	18
NGC7027	DCR	102-105	3.05 ±0.03	2.94 ±0.04	0	0
3C48	DCR	114-117	37.35 ±0.05	34.43 ±0.04	2	0
3C48	SP	118-119	37.20 ±0.02	34.08 ±0.08	2	0
3C48	ACS	120-121	41.04 ±0.15	37.16 ±0.05	12	8
3C48	ACS	122-123	41.21 ±0.20	36.50 ±0.05	12	6
3C48	DCR	135-138	35.95 ±0.01	34.24 ±0.01	-2	0
3C48	SP	159-161	37.55 ±0.05	33.35 ±0.07	2	3

Table 2: Source brightness temperatures (uncorrected for antenna gain) measured using the different GBT backends. Using the average of the DCR data as the "TRUE" temperatures, the percentage errors in the individual measurements was calculated.

ACS Configuration

The GBT spectrometer was configured for dual quadrant, dual polarization, 50 MHz bandwidth using 9 level sampling. The GO "OffOn" procedure was used. For observations of NGC7027, the data scans were composed of 11 thirty second integrations. For 3C48, the scans were composed of 3 one minute integrations.

The input level to the ACS was set by reading the Analog Filter power levels. The attenuation levels were set to yield an input power level of 1 Volt, which was thought to correspond to the optimum input power level for the ACS samplers. Recently it was determined that the optimum input level is closer to 0.25 Volts, so that the power level was a factor of 4 too high for these tests. Reducing the input power level may yield better consistency between the ACS and the other back ends.

The output spectra have 16384 channels over 50 MHz. The ACS was set up to control the switching signals to the receiver. There was no change in the attenuation levels between pairs of scans. The higher spectral resolution reveals narrow RFI features. The source of these narrow RFI features is unknown.

The ACS values in table 2 are from processing using the `spectrometer` program.

The `aips++` plots of the SP and ACS data were difficult to interpret. This was due to the GBT output format changing between data acquisition and data reduction. The new programs do not uniformly reduce the old data. More recent spectral data are properly reduced by `aips++`.

Source Brightness Temperature Comparisons

The measurements presented in Table 2 indicate that the pairs observations of the backends are self consistent. The measurement error is small in comparison to systematic differences in the measurements. There is reasonably good agreement (± 2 %) between the DCR and SP observations of 3C48, but more significant differences in the NGC7027 observations. In the case of NGC7027, the field is complex and potentially the off source position for the spectral observations may have less emission than the region scanned for the DCR measurements.

The cause of the higher apparent source brightnesses for the ACS measurements will be investigated. The ACS Off-source system temperatures were consistently lower than those values for the SP (15 K for ACS versus 19 K for the SP). This can not be explained by a miss-synchronization of the ACS and the switching of the receiver noise diodes, as any miss-synchronization would tend to reduce the measured cal signal, increasing the apparent system temperature.

The difference between ACS and SP values may be due to errors in the polynomial model calculation used to convert raw lags to a linear intensity scale. A new polynomial function is being developed.

It should be noted that using the 3C48 observations to calibrate the NGC7027 data yields better agreement with the Ott *et al.*(1994) values (ie. $S_{NGC7027} = T_{NGC7027} * S_{3C48}/T_{3C48} = 3.71 \times 16.27/41.12 = 1.47$ Jy; the Ott *et al.*1994 values is 1.37 Jy).

Conclusions

The source intensities measured by the GBT Back Ends for a moderately bright and very bright source are compared. The intensities measured with the DCR and SP are consistent to the 13 % level, without adjustment. For observations of 3C48, the DCR and SP data are in good agreement (better than 2 %). The ACS data yield consistently higher values for the source brightness temperature.

Comparing the predicted values to the measured values indicates that the DCR values are closest to the predicted. If the IF input were saturating amplifiers at some point on the chain, this would reduce the gain and compress the noise diode contribution, when the CAL diode was on. To explain the differences in measured intensity, any saturation must occur after the IF Rack.

In February 2002 it was found the the 1-2 GHz receiver gain was somewhat unstable, the receiver was removed from the telescope and some cracked connections were repaired. Through VLBI observations it was found that the X and Y linear polarizations were swapped. This helps explain the difference in X and Y polarized intensities measured here. The measured Y values should be greater than the X values, since the X noise diode temperature is 2 % larger.

Reducing the input power levels to the SP and ACS might have yielded measurements that were in closer agreement.

Future tests will be performed after hardware and software checks of the backends are complete.

Example of DCR PEAK data displayed by **aips++**

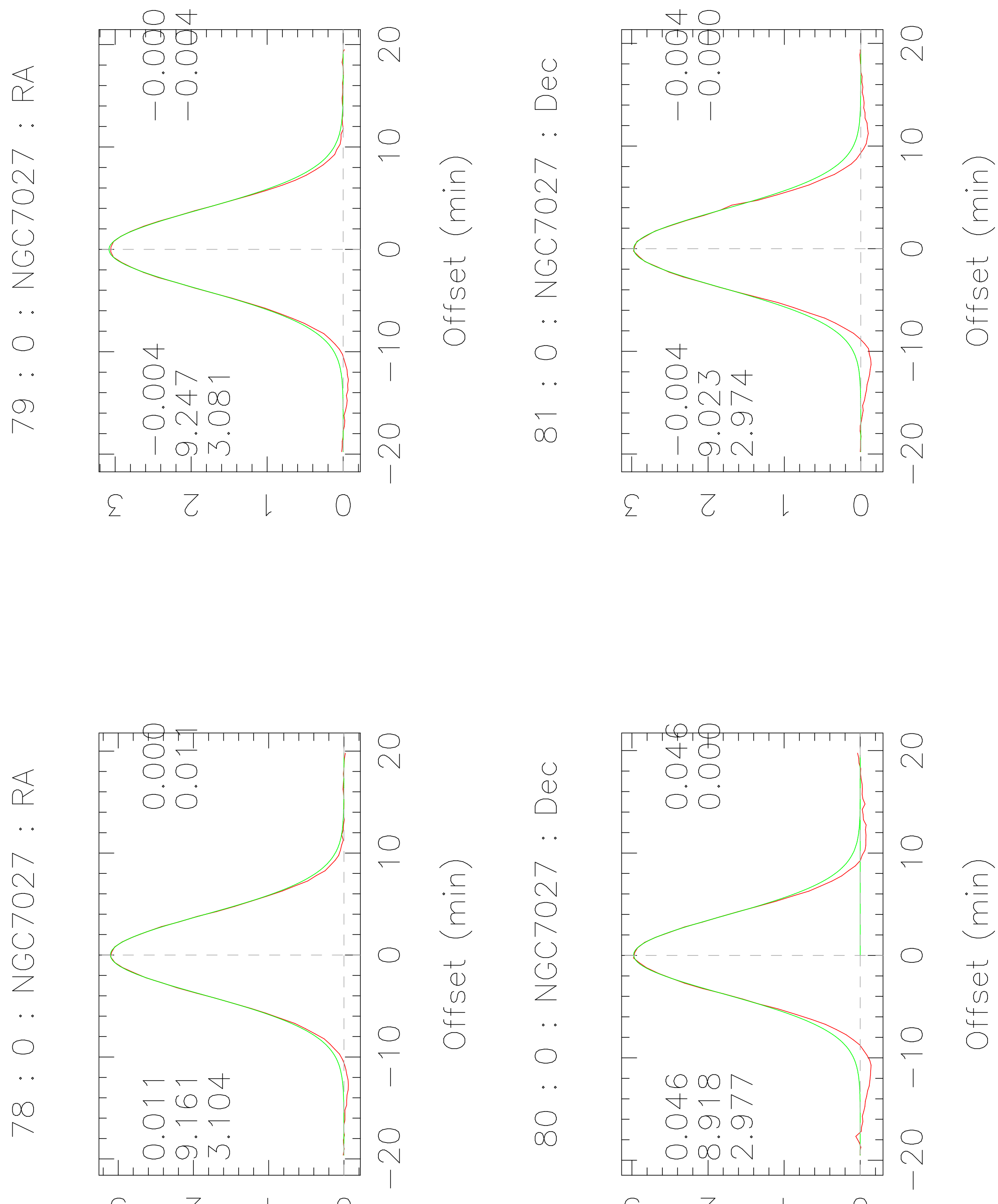

Figure 1: DCR Linearly X Polarization observations of the source NGC7027. The four plots are from four separate scans across the source. The red curves show the data and the green curves show the Gaussian fits.

Example of Spectral Processor data displayed by **aips++**

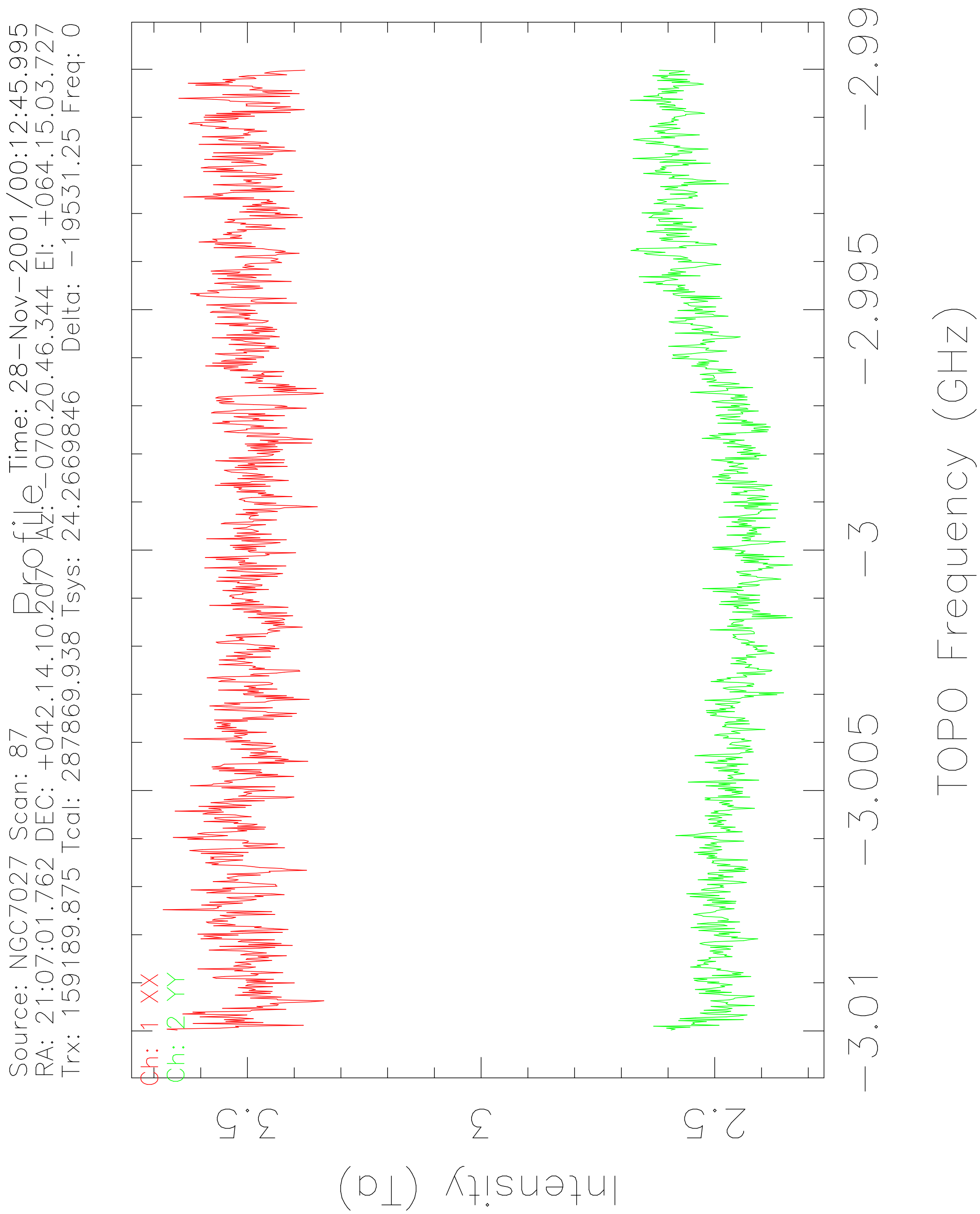

Figure 2: Spectral Processor observations of source NGC7027. The difference in the intensities of the two polarizations is not reasonable. The upper (red) curve is X polarization and lower (green) curve is Y polarization. The frequency span along the X axis (20 MHz) is correct, but the center frequency is incorrect.

Example of Spectral Processor data displayed by `spectrometer`

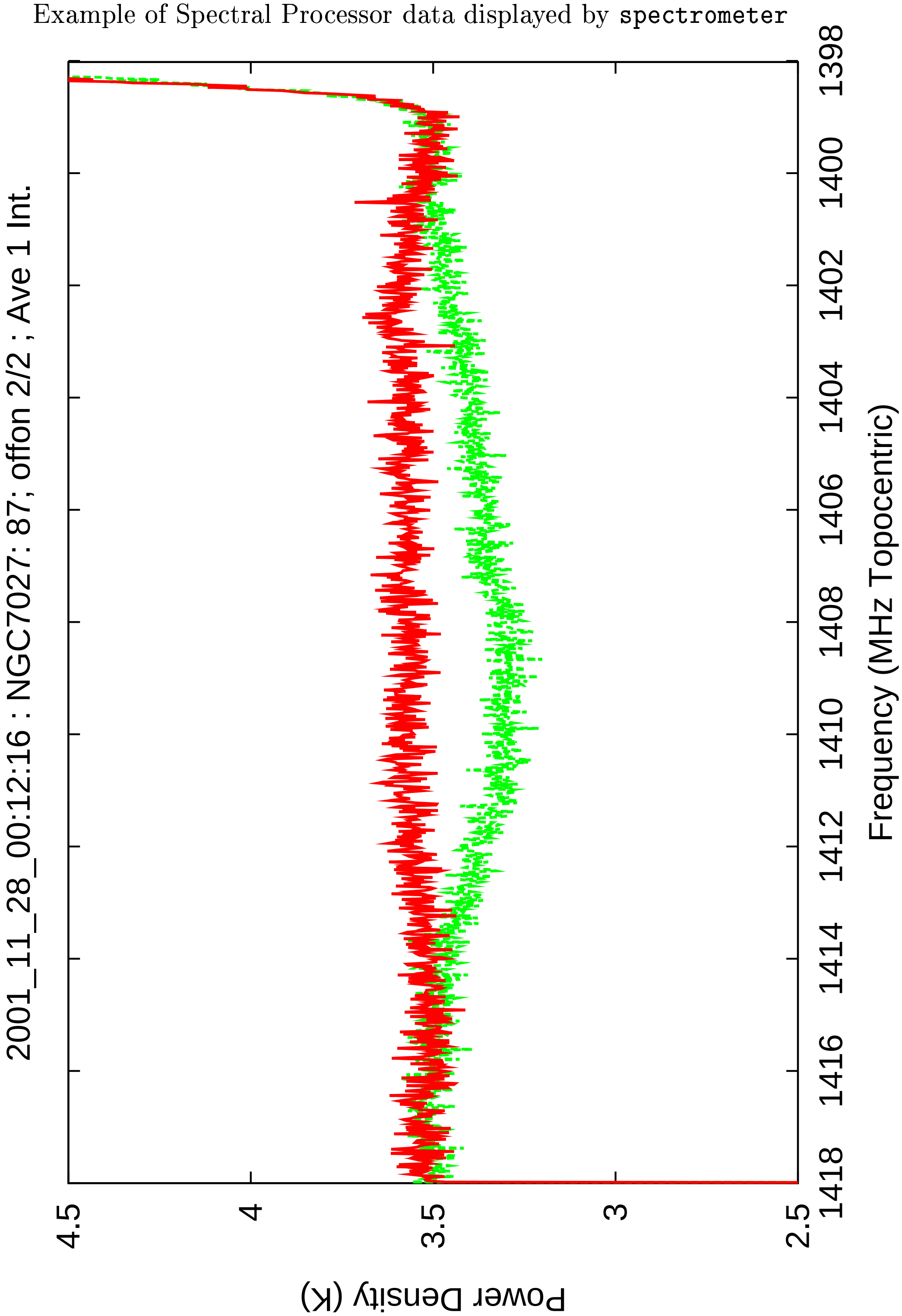

Figure 3: Spectral Processor observations of source NGC7027. The upper curve (red) curve shows the average of the Cal On and Cal Off X polarization data, after correcting for the Cal On signal. The lower curve (green) shows the average of the Y polarization signals.

Example of Spectrometer data displayed by `spectrometer`

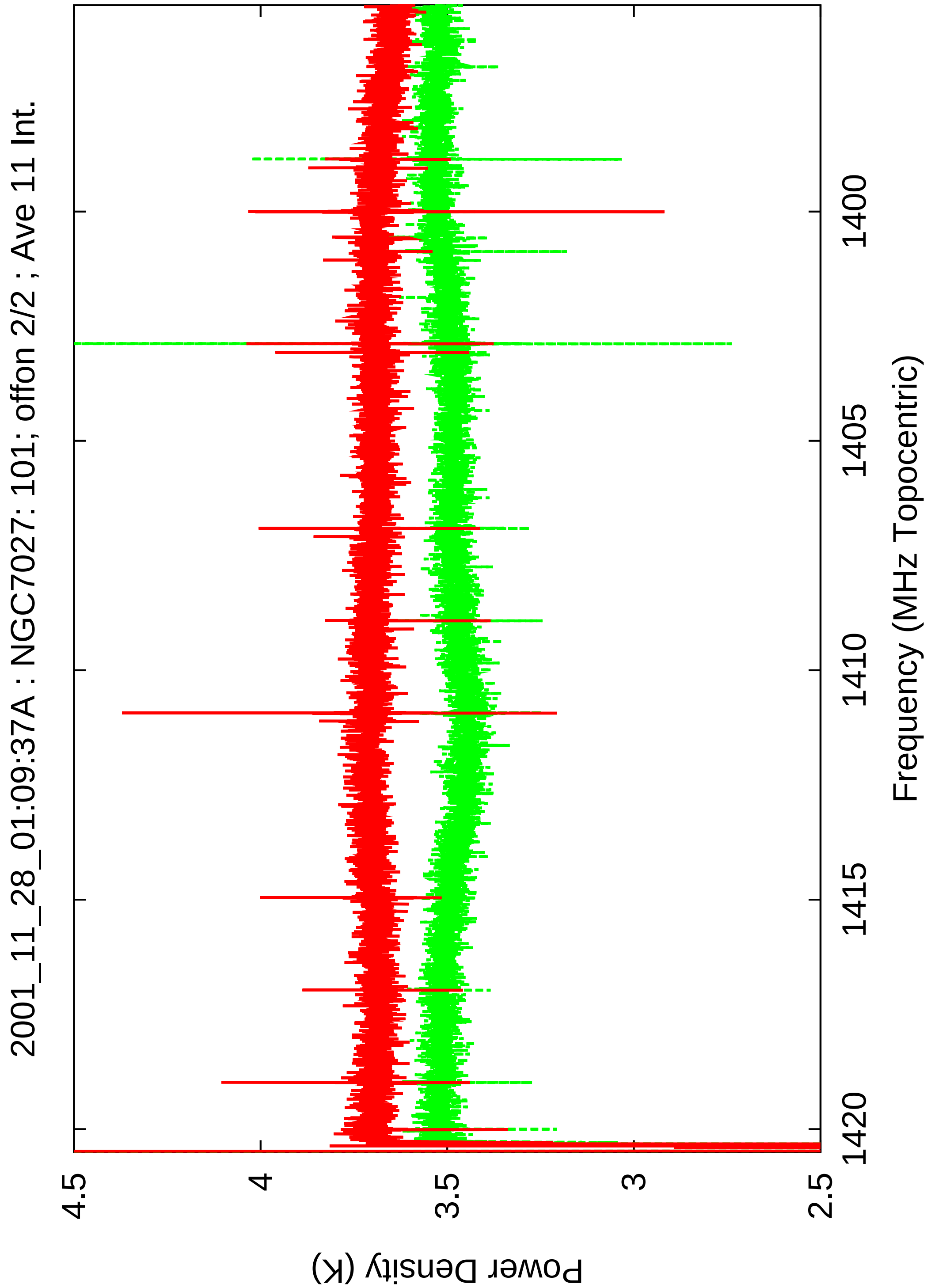

Figure 4: Spectrometer observations of source NGC7027. The upper curve (red) curve shows the average of the Cal On and Cal Off X polarization data, after correcting for the Cal On signal. The lower curve (green) shows the average of the Y polarization signals.

Example of Spectrometer data displayed by `spectrometer`

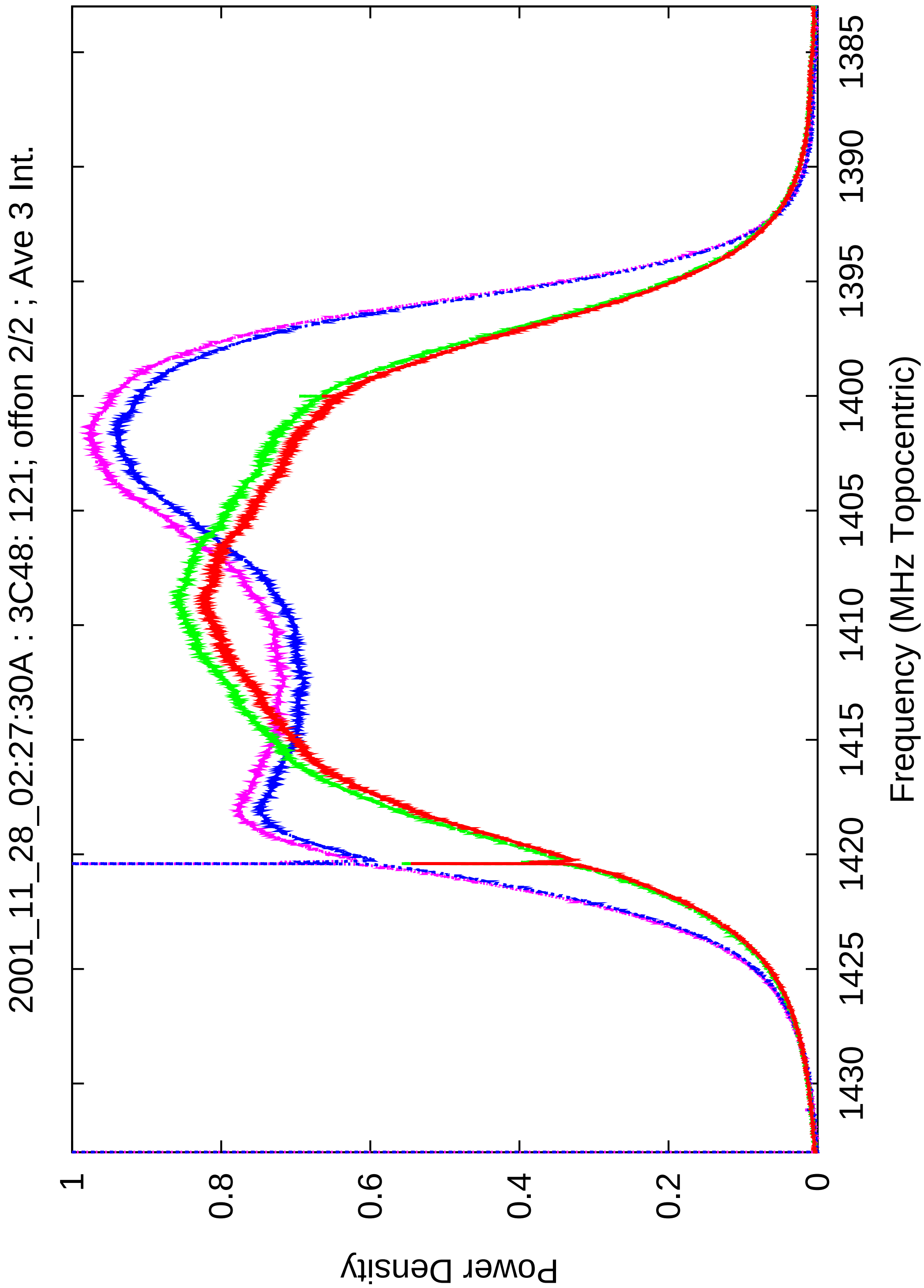

Figure 5: Un-calibrated observations of 3C48, showing the spectral band pass of the input to the DCR (and other backends). The curves with "one hump" (red and green) are X polarization data with Cal noise diode On and Off. The other two curves (pink and blue) are Y polarization data with Cal On and Cal Off. Notice the galactic neutral hydrogen emission at 1420.4 MHz. Note that the -10 dB points are 17 MHz from the center frequency (total bandwidth 34 MHz for the 20 MHz filter).

Example of Spectrometer data displayed by `aips++`

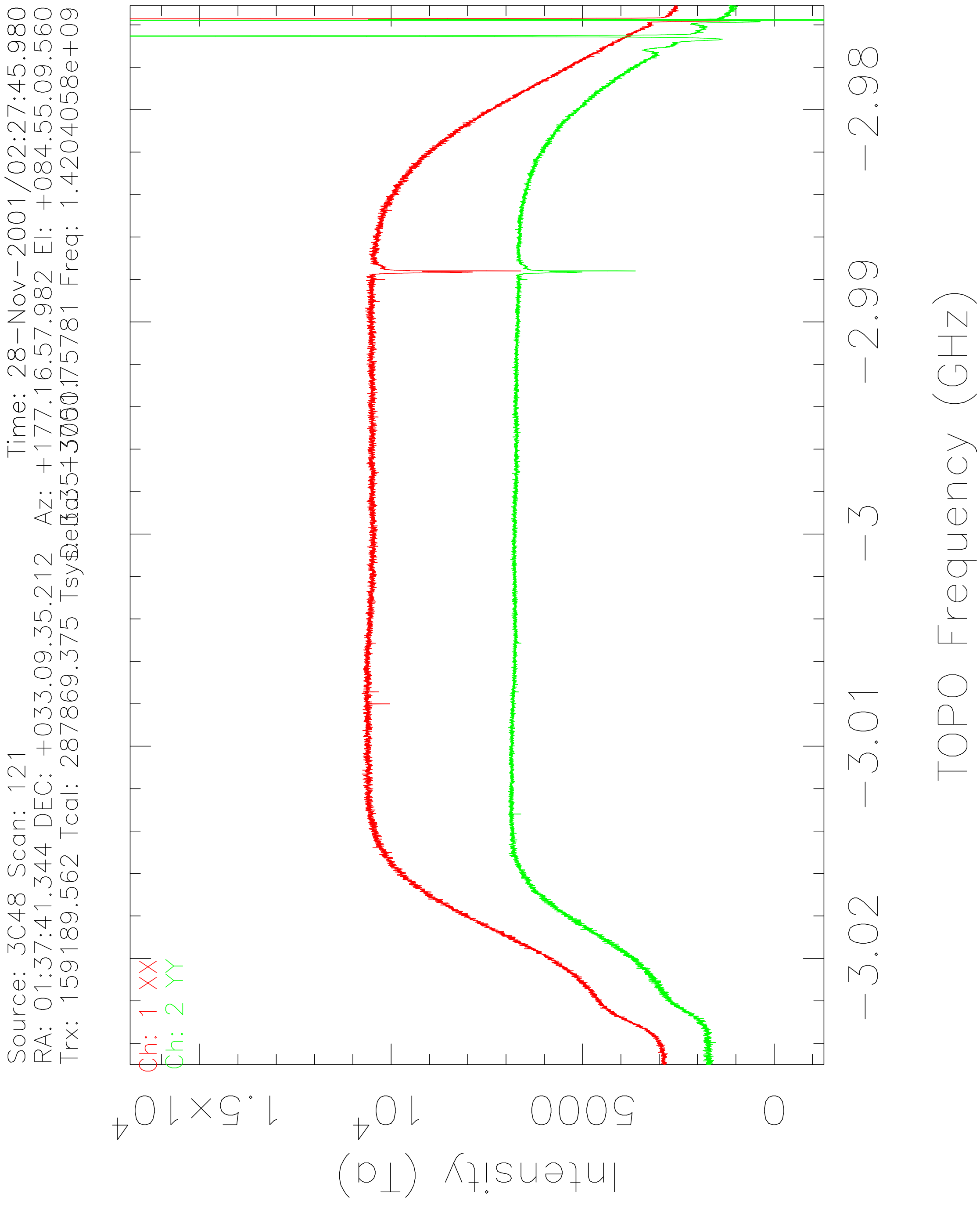

Figure 6: Calibrated observations of 3C48, showing the spectral band pass of the input to the DCR (and other backends). This plot was produced by `aips++`. The spectral intensity scale and frequency axis have calibration errors due to changes in the programs to support the new format GBT FITS format output files. The difference in the intensities of the two polarizations is not reasonable. The upper (red) curve is X polarization and lower (green) curve is Y polarization. The frequency span along the X axis (20 MHz) is correct, but the center frequency is incorrect.