Prime Focus 2 Receiver

Radio Frequency Interference Scan

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Abstract

This note presents a summary of the Radio Frequency Interference (RFI) in the Prime Focus 2 (PF2) receiver frequency range 900 to 1250 MHz. Heavy RFI is only seen in 125 MHz of the "official" 320 MHz PF2 bandpass from 910 to 1230 MHz. The 958-1024 MHz range is virtually free of strong RFI. Also note that the peak intensity of the PF2 RFI is significantly lower than as seen in the Prime Focus 1 (PF1) band, suggesting that front end amplifier saturation and system dynamic range issues are of less a concern for PF2 than PF1.

This document provides a set of plots of the RFI spectral intensity as a guide for determining optimum frequency ranges for observations with PF2. Because RFI is expected to be time variable three observations are presented, in the evening, at 18:50 EDT. one in the evening 21:00 EDT and the third at midnight. The midnight spectra show significantly less RFI.

1 Introduction

These data were taken to test the proper operation of the Prime Focus 2 receiver in advance of use by visiting astronomers. The functionality of the receiver hardware was confirmed. Items checked included 1) operations of both the high and low calibration sources, 2) linear and circular polarization configurations and 3) band pass filters after the first down conversion.

Test observations were made on 2004 April 30, May 1 and May 4. Additional tests were made by Rick Fisher, which will be described elsewhere. Observations of radio source 3C286 (Ott *et al.*1994), made to determine the effective calibration noise diode intensities in units of (Jy/η_A), where η_A is the gain of the GBT. Additional observations of a weak source were made to test the proper decrease of noise level with increasing integration time. A short set of observations were made during the early evening to check the RFI environment, when aircraft traffic is expected to be high.

The data presented here were made using the low calibration source, the GBT IF system and the Auto-Correlation Spectrometer (ACS).

These data were reduced using IDL procedures combined into a package called **GBT_IDL** , written by Tom Bania and Glen Langston (see `http://wwwlocal.gb.nrao.edu/~glangsto/idl`).

Documentation on the GBT RFI environment may be found at:
`http://www.gb.nrao.edu/IPG/`,
`http://wwwlocal.gb.nrao.edu/~glangsto/rfi`
`http://www.gb.nrao.edu/~fghigo/rfi_pf/rfi.html`

2 Observation Setup

Most of the checkout observations with the Prime Focus 2 (PF2) receiver were made on April 30, 2004. The system was configured using `config_tool` and observations were initiated using `GO_LITE`. After initial configuration, the ACS was reconfigured using `CLEO` for the ACS A1 B1 C1 D1 mode. The GBT LO was configured for no Doppler tracking (ie. the topocentric frame).

The ACS banks A and B were configured for 200 MHz bandwidth observations. The two 200 MHz bands ACS bands were provided with IF signals separated by 150 MHz, so that almost all of the PF2 band could be simultaneously observed. The ACS sky center frequencies were 1000 and 1150 MHz. Figures 1, 3 and 5 show the raw band pass spectrum over the frequency range 900 to 1250 MHz. Figures 2, 4 and 6 are centered on 1090 MHz, the location of the strongest RFI feature

in the band. The peak intensity in figures 1 and 2 is 16 counts, corresponding to an RFI line peak intensity of approximately 300 K.

The overall band pass shape is due to the 240 MHz wide first IF band pass filter, centered on sky frequency 1075 MHz. The two ACS banks are band limited by 200 MHz wide filters in the analog filter rack prior to the ACS high speed sampler.

During the observations on April 30/May 1, the third ACS bank, C, was set up for 50 MHz, 9 level mode and the fourth ACS bank, D, was set up 12.5 MHz 9 level mode. The center frequency for the 50 MHz band was 1125 MHz and 1131.25 MHz for the ACS band 12.5 MHz wide.

During observations of scan 48 on 2004 April 30, the GBT IF was configured to inject a weak test tone at 1132 MHz, to confirm the IF chain calculations. This test tone was detected at the correct frequency. The frequency of the test tone was measured for 12.5, 50 and 200 MHz ACS modes. For the 12.5 MHz mode, the frequency measured with **GBT_IDL** was 1132.000±0.0005 MHz and the channel separation was 1526 Hz. For the 50 MHz ACS mode, the test tone was at 1131.999±0.006 and the channel separation was 6,104 Hz. For the 200 MHz ACS mode, the test tone was at 1131.998±0.085 and the channel separation was 24,417 Hz. Figure 7 shows the Gaussian fit to the 50 MHz band ACS observation.

3 RFI Survey Summary

For the PF2 receiver, the heaviest RFI will be seen in the 1025 - 1150 MHz range. This is air-to-ground transmissions from aircraft Distance Measuring Equipment (DME) and the air-to-ground transponder at 1090 MHz. The Ground-to-air DME transmissions occur in the ranges of 962-1024 MHz and 1151-1213 MHz, but Green Bank benefits from substantial diffraction loss in the signal path from most ground stations. Thus, RFI in these ranges is seldom seen. The relatively strong lines seen at 1170 and 1178.35 are noted and we are looking into them.

R. Fisher (private communication) indicates the strong RFI, seen in Figures 1-6, at 1090 MHz is produced by aircraft transponders. The transponder signal is sent by aircraft in response to ground station (probably Bedford, VA in this case) queries on 1030 MHz, also seen on this data. This set of frequencies is used by all aircraft and airports. It is expected that 1090 MHz will have RFI for integration times longer than a few micro-seconds. R. Fisher noted that activity in the 1025 - 1150 MHz range quiets down considerably late at night. This is understandable due to passenger flight schedules. We tested this by observations at three different times of day, and expect that the interval between midnight and 6:00 AM EDT will be relatively quiet.

Figures 1 and 2 show the RFI during peak air traffic times. These data are from scan 7 on 2004 May 04 at 18:30 EDT and part of GBT project `TPF2_040504`.

Figure 3 shows the same frequency range as figure 1, but was taken at a later time, 21:00 EDT. Figure 4 is centered on the strongest feature in the band, centered on 1090 MHz. These data are from scan 48 on 2004 Apr 30 at 20:43 EDT and are part of GBT project `TPF2_040430`.

Figure 5 shows the same frequency range as figure 1, but was taken at midnight. Figure 6 shows is centered on the strongest feature in the band, centered on 1090 MHz. These data are from scan 114 on 2004 May 01 at 0:20 EDT (midnight) and are part of GBT project `TPF2_040430`.

The Interference Protection Group (IPG) found that RFI was seldom detected in the 958-1024 MHz range during monitoring sessions at the RFI monitoring station. The IPG monitoring occurred on several different days and at different times of day. The IPG is also looking into the lines at 945, 946, 953.39, and 957.56 MHz.

Figures 9 to 40 show the raw spectral intensity of RFI in this frequency range. Nominally the raw counts have a band center nominal intensity of 1 in an RFI free region, where the system temperature during the off-source observation was approximately 25 K. The raw spectra intensity may be approximately converted to Kelvins assuming 0.05 counts corresponds to 1 K. The spectra have a median filtered baseline subtracted to set RFI-free intensity near zero. The median filter full width is was 1 MHz. The total observing time in this scan is 1 minute.

4 GBT Antenna Efficiency at PF2

A quick check of the GBT efficiency at 1000 and 1150 MHz was made by `OnOff` observations of 3C286 calibrated by

$$T_{A,3C286} = T_{Sys-Reference}(V_{Signal} - V_{Reference})/V_{Reference},$$

where $T_{A,3C286}$ is the 3C286 antenna temperature, $T_{Sys-Reference}$ is the antenna temperature of the reference scan, V_{Signal} is the raw ACS intensity towards 3C286, and $V_{Reference}$ is the raw ACS intensity towards a reference position near 3C286. $T_{A,3C286}$ average of both polarizations is shown in Figure 8.

For 3C286 at 1000 MHz we observe $T_{A,X} = 30.53 \pm 0.05$ K and $T_{A,Y} = 33.93 \pm 0.05$ K. Note that 3C286 is approximately 10 % linearly polarizes so part of the difference between intensities may be explained by polarization. Also part difference is due to uncertainty in measurement of the effective temperature of the calibration noise diodes. We adopt the average X and Y linear polarization temperature for antenna temperature and take the difference between the temperature of the average and the difference of the polarizations as an estimate of the error in the antenna temperature (Ie. $T_A(1000MHz) = \frac{1}{2}[(T_X + T_Y) \pm (T_Y - T_X)] = 32.23 \pm 1.7$). The spectral intensities were measured in 1 MHz RFI free bands near the center of the 200 MHz band passes.

For 3C286 at 1150 MHz we observe $T_{A,X} = 26.54 \pm 0.03$ K and $T_{A,Y} = 33.00 \pm 0.04$ K. Therefore we adopt $T_A(1150MHz) = 29.77 \pm 3.2$). The Ott *et al.*1994 flux density for 3C286 is 16.92 ± 1.05 Jy at 900 MHz and 15.97 ± 1.01 at 1150 MHz. Using the equations of Langston etal 2004, yields the aperture efficiency, $\eta_A(\nu)$:

$$\eta_A(1000MHz) = \frac{2761 \times 5.584 \pm 0.075}{16.92 \pm 1.05 \times 7854} = \frac{1}{2.845} \times \frac{32.23 \pm 1.7}{16.92 \pm 1.05} = 0.67 \pm 0.06,$$

and

$$\eta_A(1150MHz) = \frac{1}{2.845} \times \frac{29.77 \pm 3.2}{15.97 \pm 1.01} = 0.66 \pm 0.07,$$

where the uncertainty in η_A is due roughly equally to the polarization effects and the uncertainty in the flux density of 3C286. Atmospheric and Ionospheric attenuation are ignored in this estimate.

Also note that these observations were made before the `GO_LITE` fix for PF2 focus control was installed. These observations were made with the PF2 Focus fixed at 700 mm. Later observations showed that a more optimum focus was 525 mm. Including attenuation effects an setting the focus to the optimum value would both improve the estimates of η_A.

5 Summary

RFI is present in much of the PF2 band, but with intensity significantly less than the RFI peak intensities for the 300 to 900 MHz frequency range. The band scan spectra shown here should be useful for considering the feasibility of observations.

We note that the frequency range 958-1024 MHz is generally free of strong RFI and that RFI in the frequency range 1025 - 1150 MHz is significantly reduced after midnight EDT.

Note that even in the very strong RFI regions, with clever data sampling and processing, it may be possible to observe faint radio sources. Rick Fisher is developing a system for high frequency sampling, RFI identification and rejection.

Further checks of RFI are needed at many different times of day (ie noon, late night, early morning etc) to determine when observations are feasible using PF2. The aperture efficiency measurements should also be repeated with optimum PF2 focus and over a wider frequency range to determine the extreme limits of PF2 sky frequency operations.

6 References

1. Fisher, J. R. "Signal Analysis and Blanking Experiments on DME Interference" April 5, 2004.
2. "Apparent Temperature of Mercury, Mars, Saturn and Venus at X Band" Langston, G., Braatz, J., Ghigo, F., Maddalena, R., Minter, A. and O'Neal, K, March 2, 2004
3. Ott, M. Witzel, A., Quirrenbach, A., Kirchbaum, T.P. Standke, K., J., Schalinski, C. J., and Hummel, C.A., (1994) Astronomy and Astrophysics, Vol 284 pg 331.

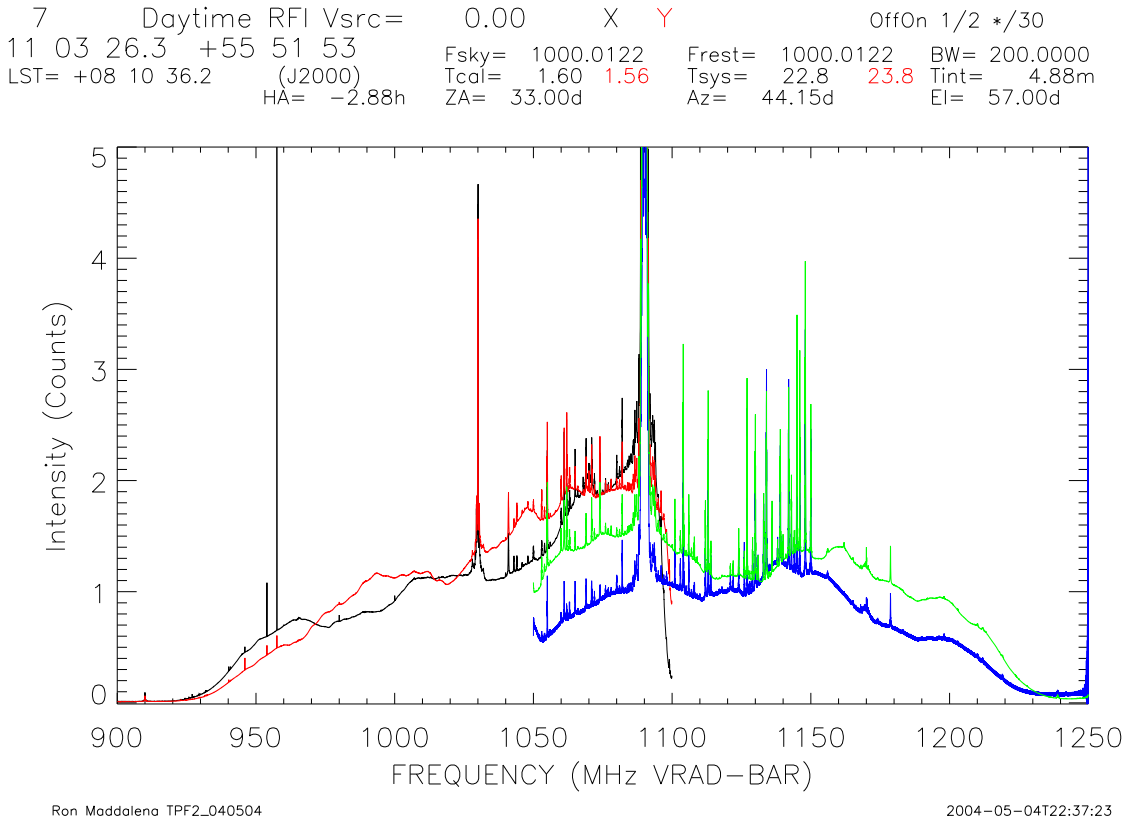

Figure 1: Raw Counts vs Frequency plot for observations of empty sky. The observation was made in dual 200 MHz ACS mode with spectral bands offset by 150 MHz. These observations were made at 18:40 EDT, when airplane traffic is expected to be high. Peak intensity is 16 Counts.

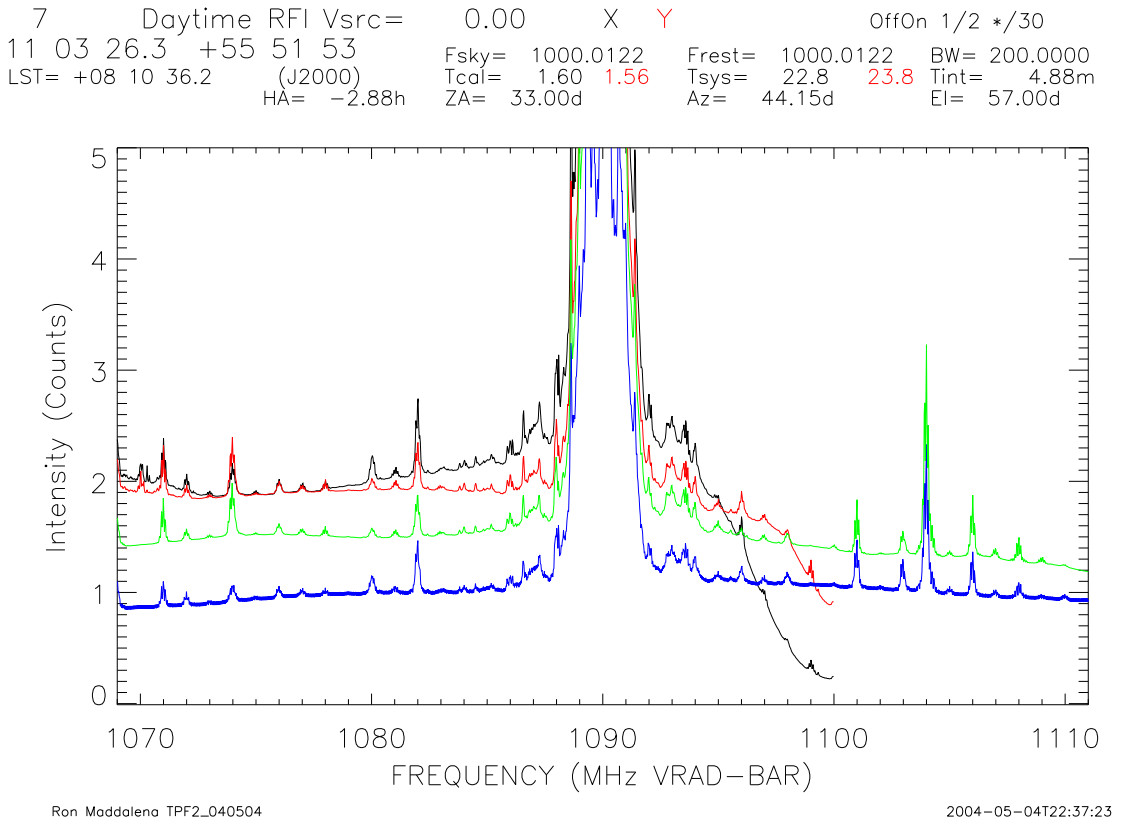

Figure 2: Same as previous plot except centered on the strongest RFI feature at 1090 MHz. Raw Counts vs Frequency plot for observations of empty sky.

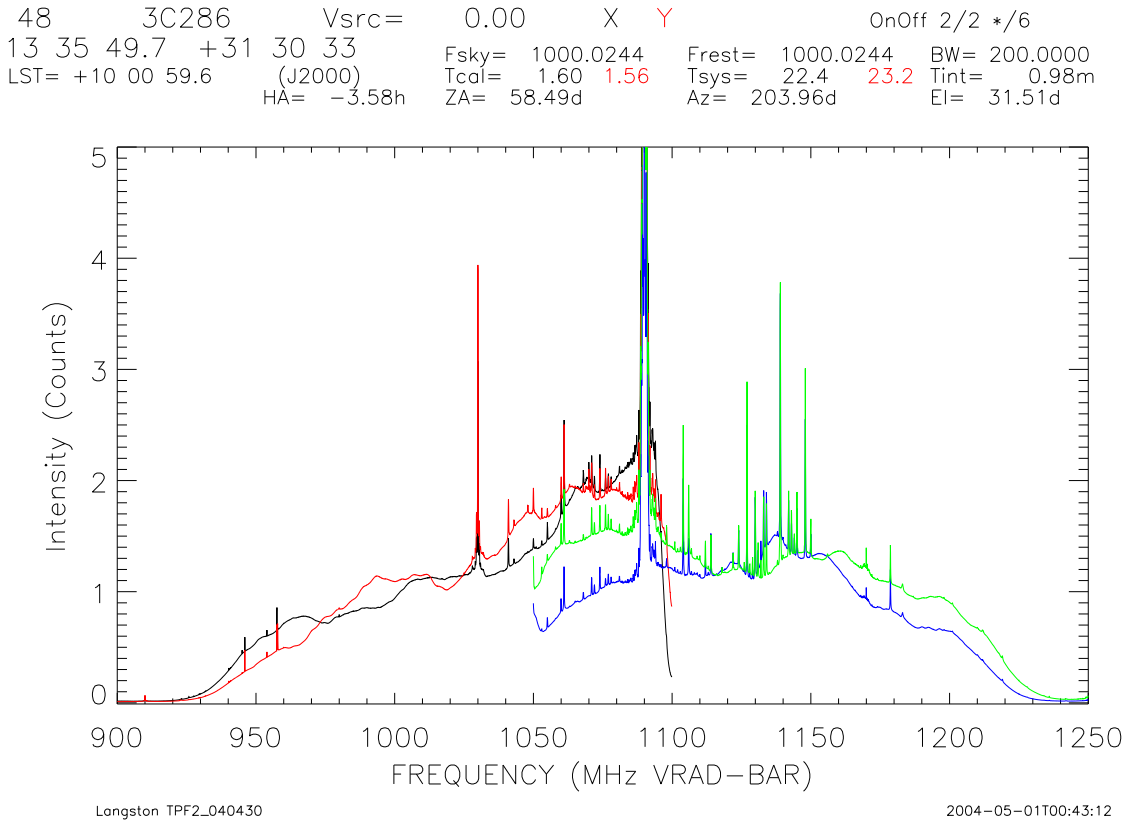

Figure 3: Raw Counts vs Frequency plot for observations of empty sky. The observation was made in dual 200 MHz spectrometer mode with spectral bands offset by 150 MHz. These observations were made just before 21:00 EDT.

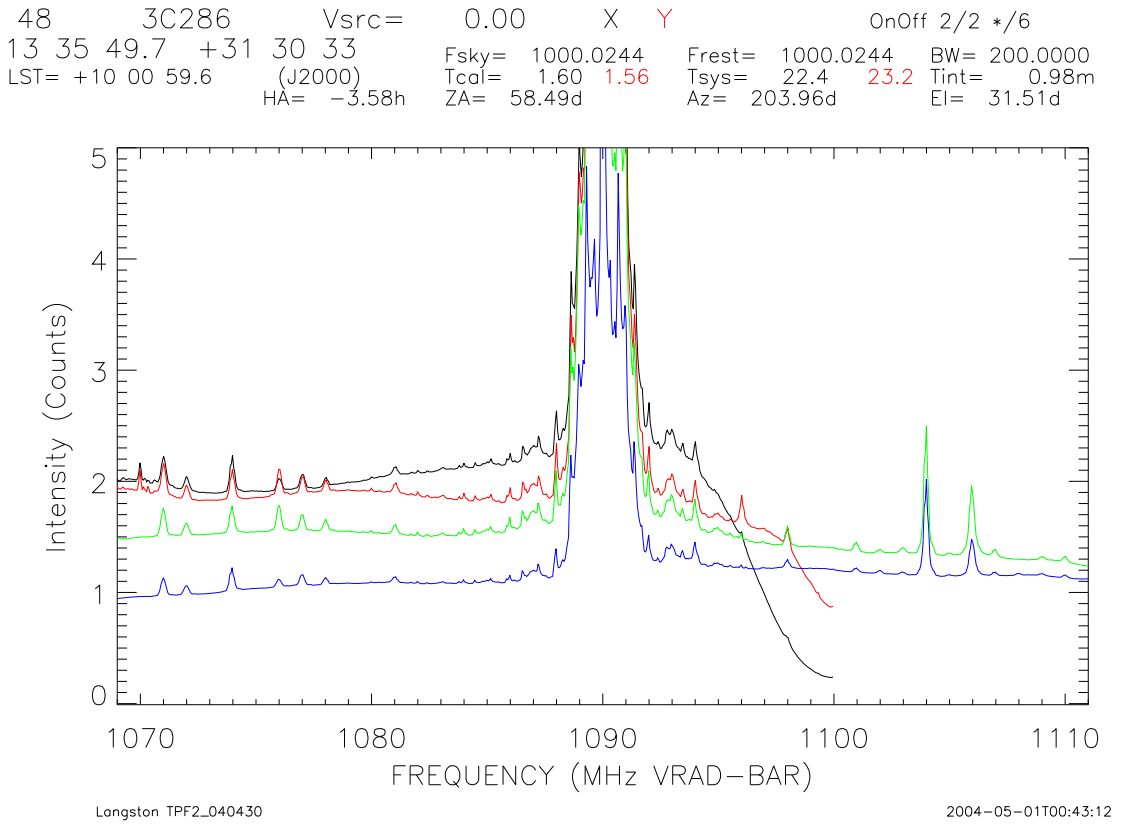

Figure 4: Same as previous plot except centered on the strongest RFI feature at 1090 MHz. Raw Counts vs Frequency plot for observations of empty sky.

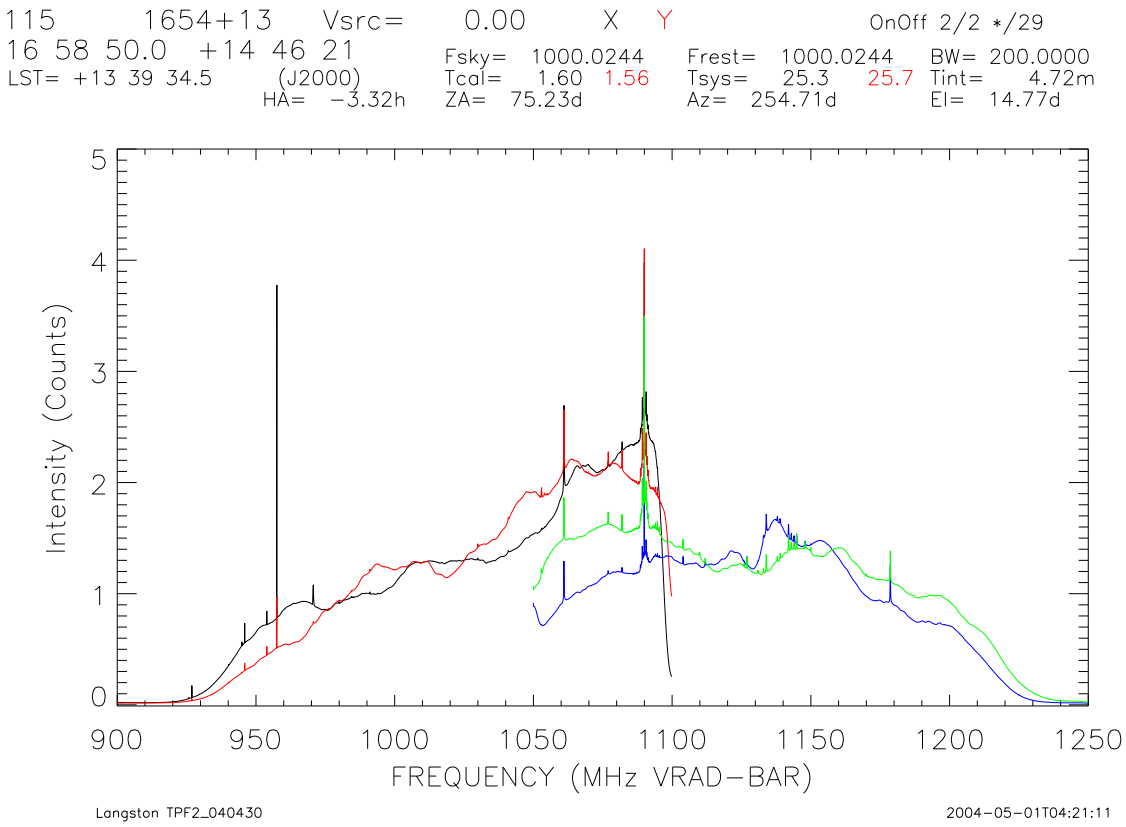

Figure 5: Raw Counts vs Frequency plot for observations of empty sky. The observation was made in dual 200 MHz spectrometer mode with spectral bands offset by 150 MHz. These observations were made just after midnight EDT, when airplane traffic is expected to be low.

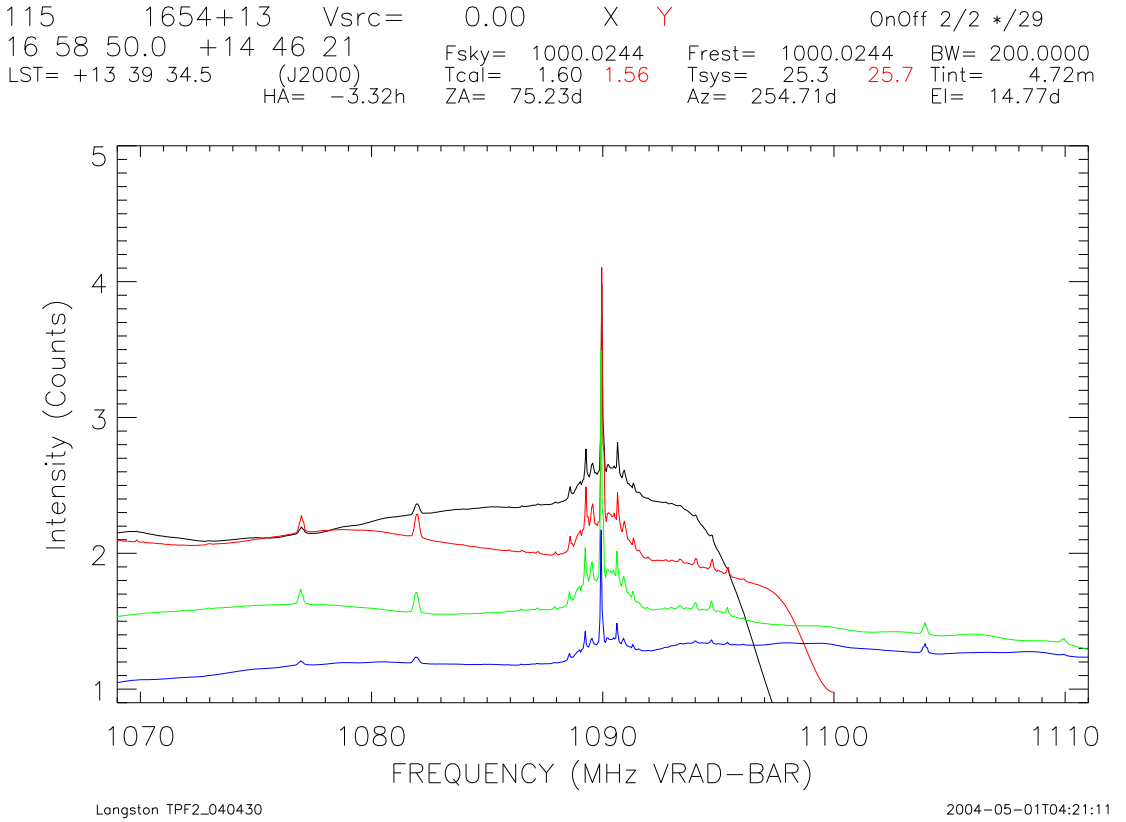

Figure 6: Same as previous plot except centered on the strongest RFI feature at 1090 MHz. Raw Counts vs Frequency plot for observations of empty sky.

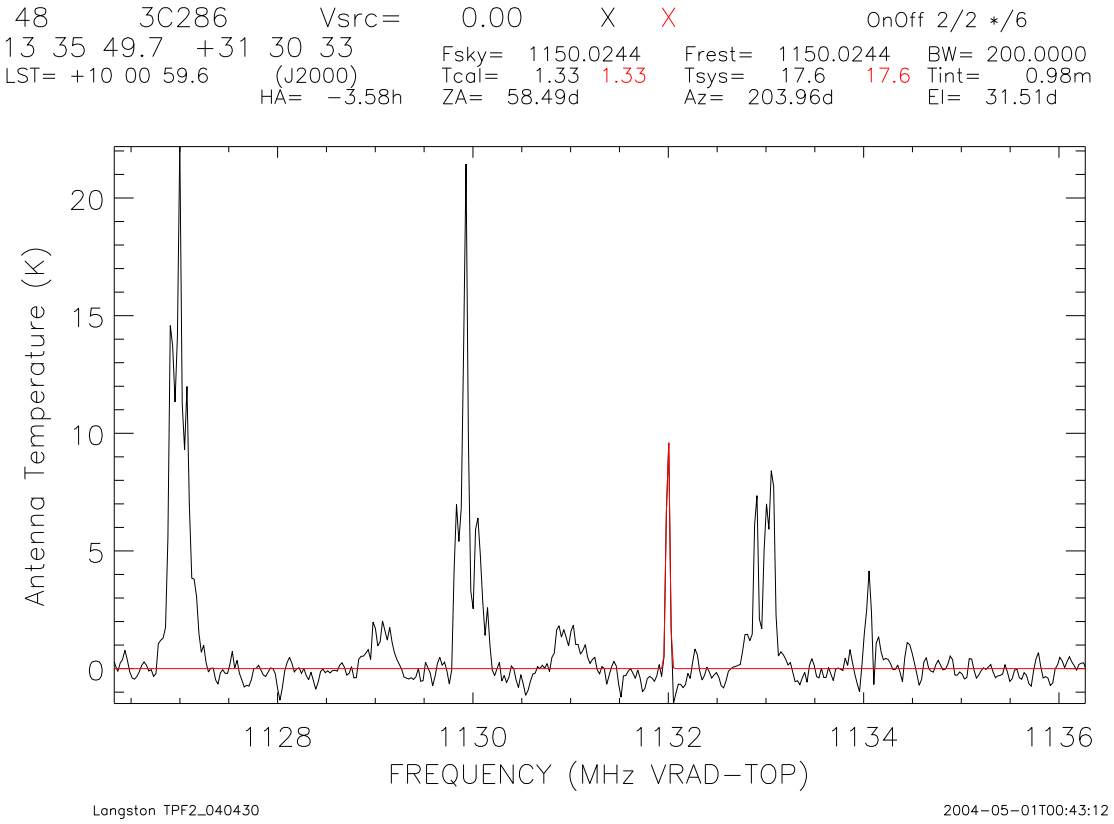

Figure 7: Spectral intensity versus frequency plot, with fit to test tone at 1132 MHz. The tone is found at the correct frequency to within a small fraction of a channel. The channel spacing for this ACS mode is 24.4 kHz.

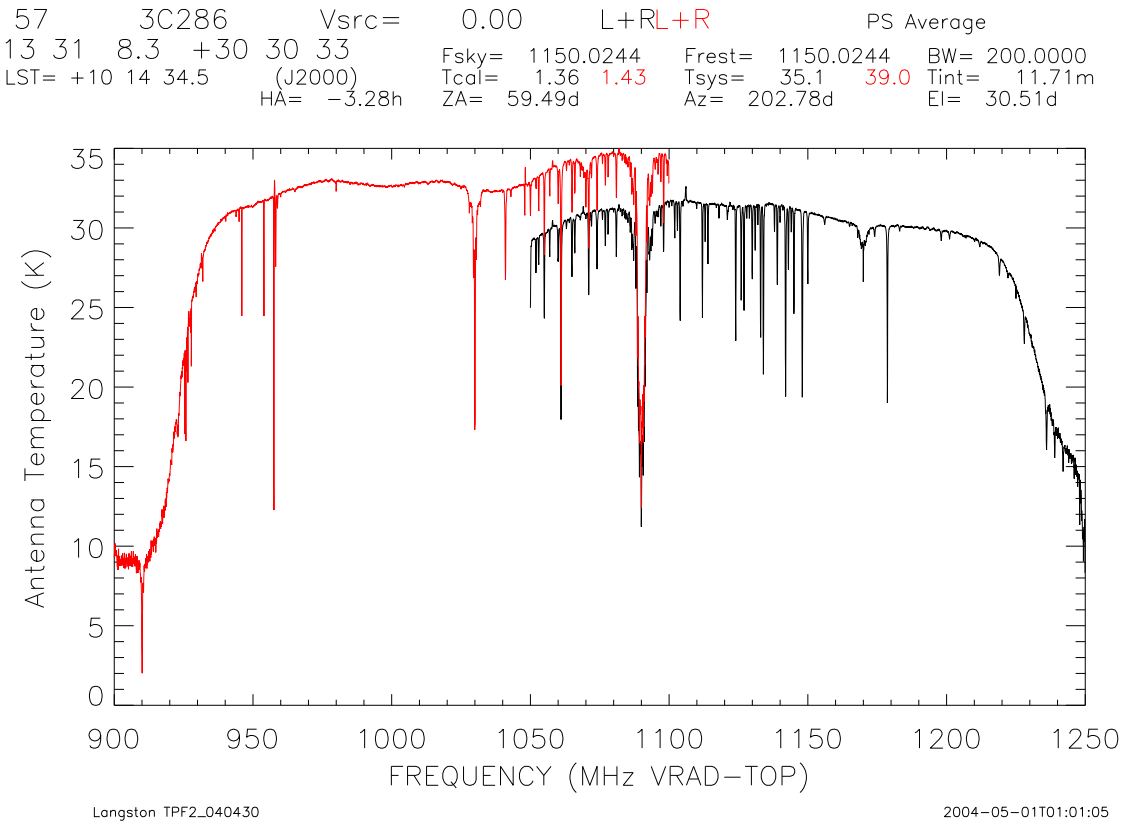

Figure 8: Source 3C286 spectral intensity versus frequency, calibrated using calibration noise diode values measured in the lab.

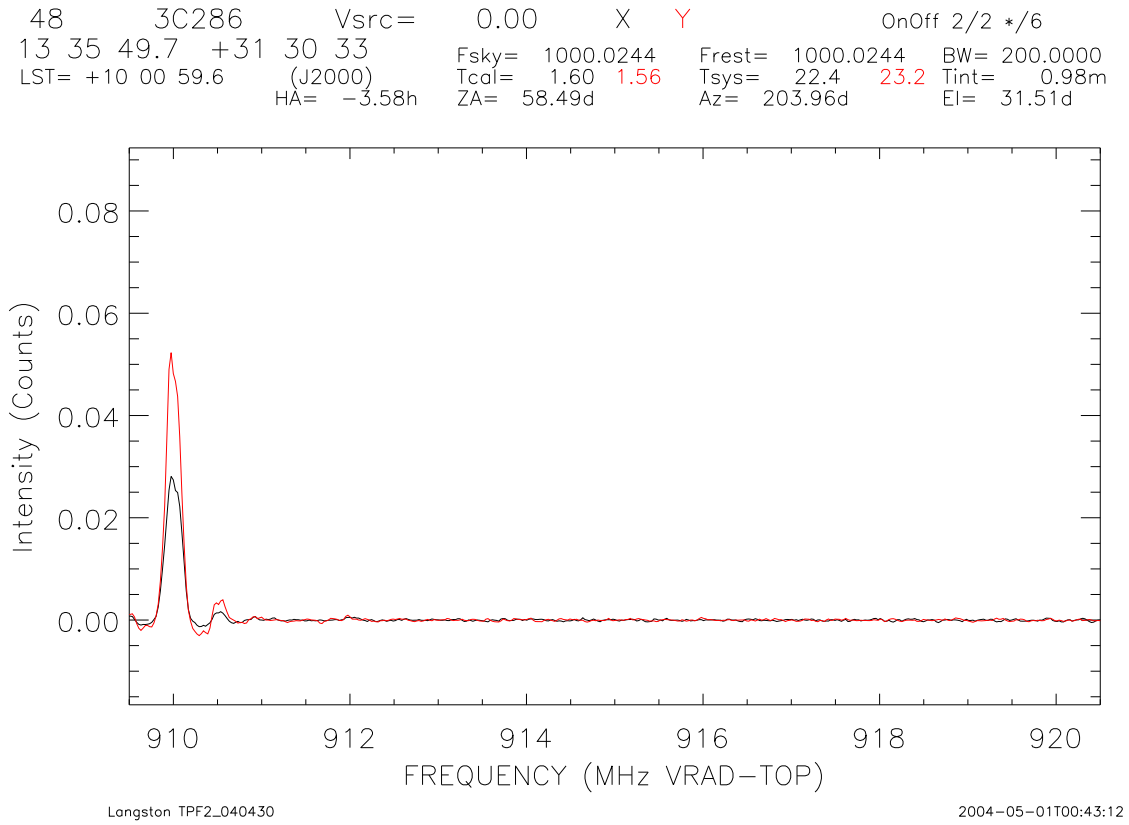

Figure 9: Raw Intensity vs Frequency Plot for dual linear polarization observations.

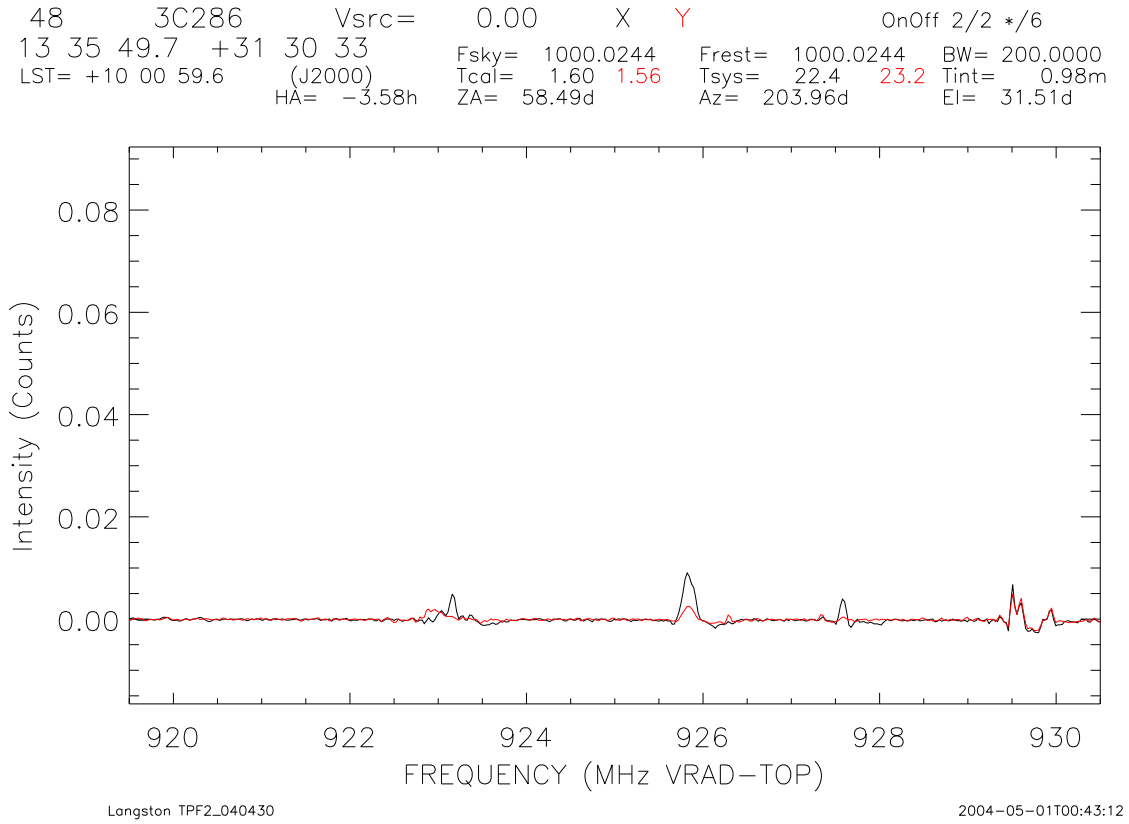

Figure 10: Raw Intensity vs Frequency Plot for dual linear polarization observations.

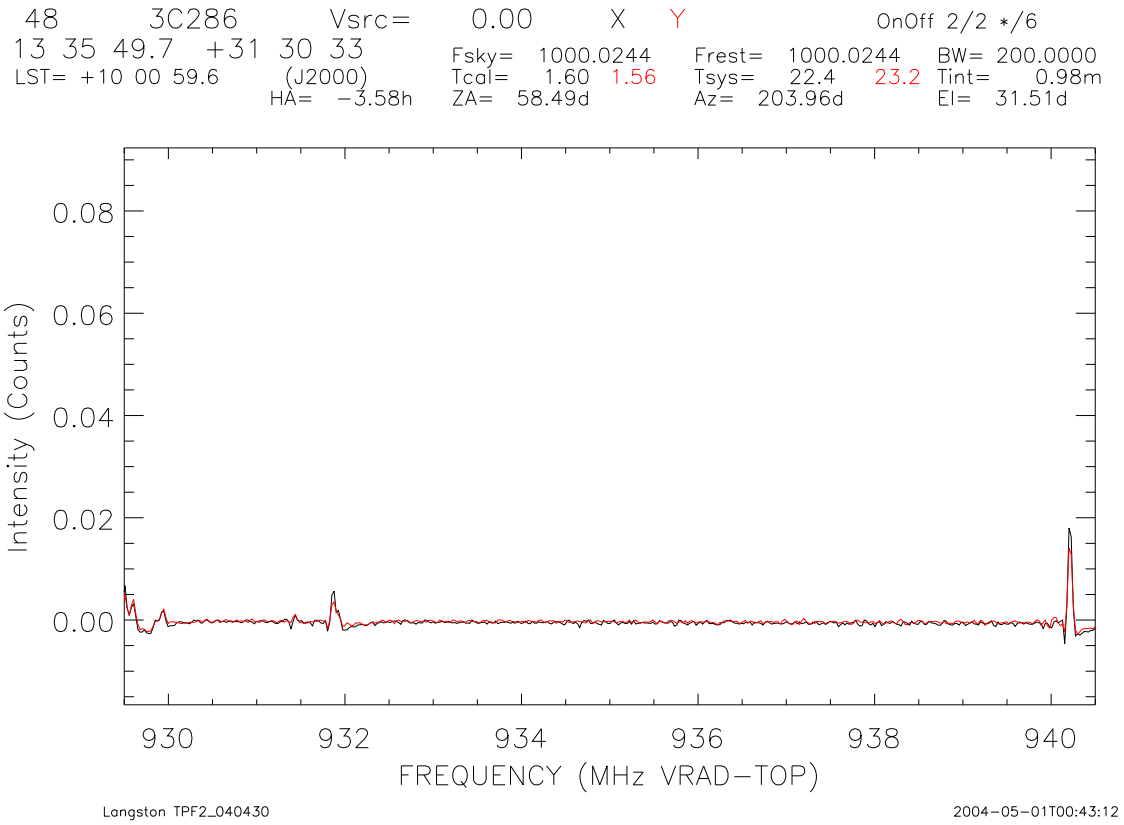

Figure 11: Raw Intensity vs Frequency Plot for dual linear polarization observations.

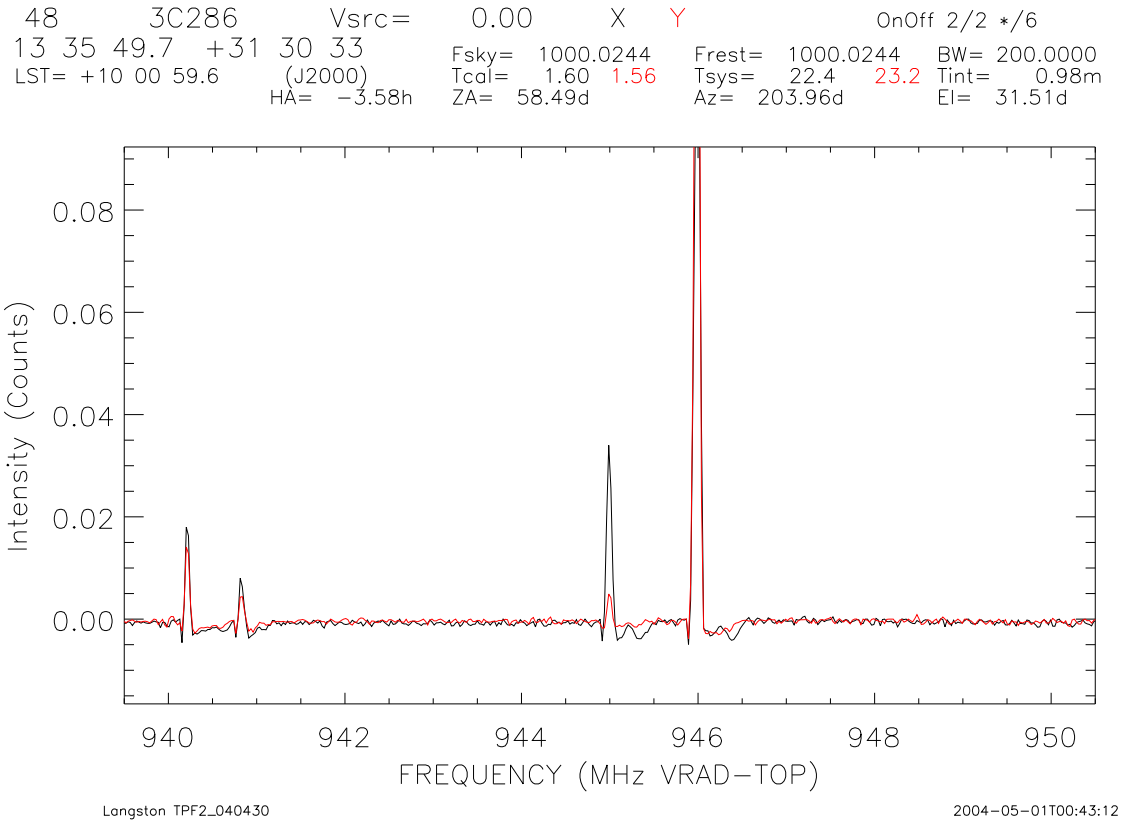

Figure 12: Raw Intensity vs Frequency Plot for dual linear polarization observations.

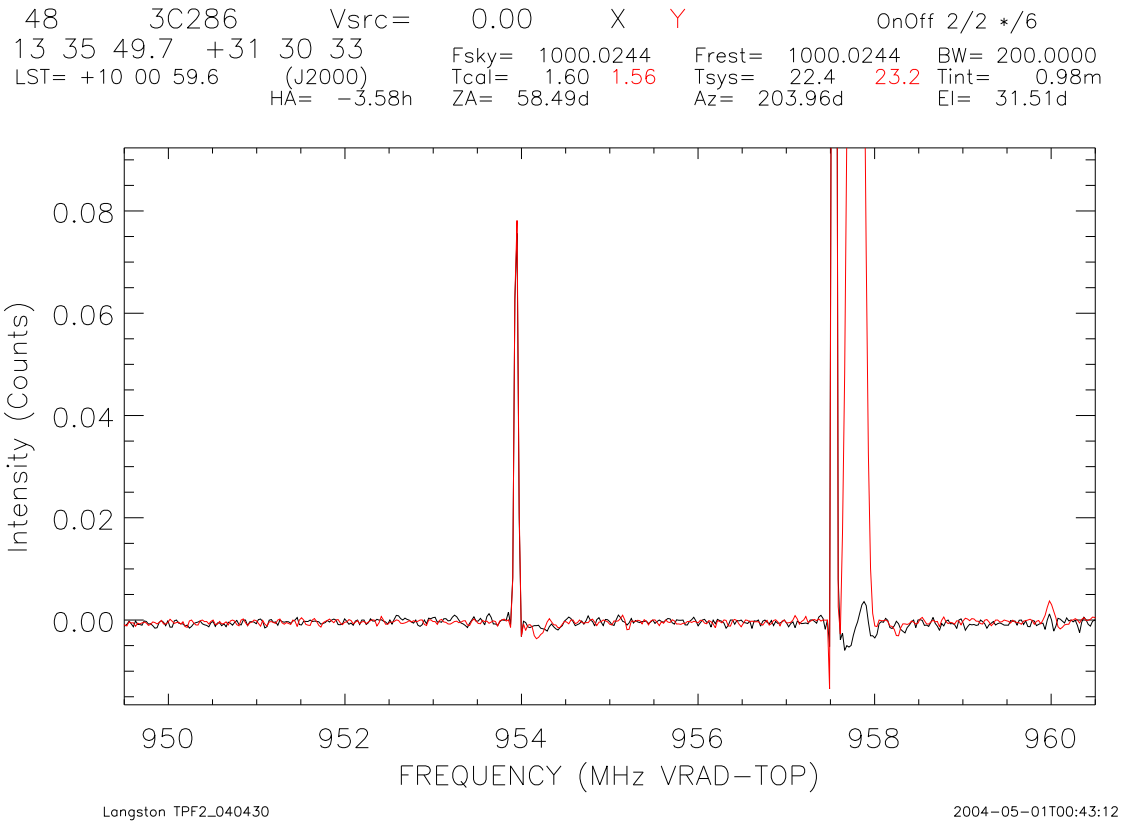

Figure 13: Raw Intensity vs Frequency Plot for dual linear polarization observations.

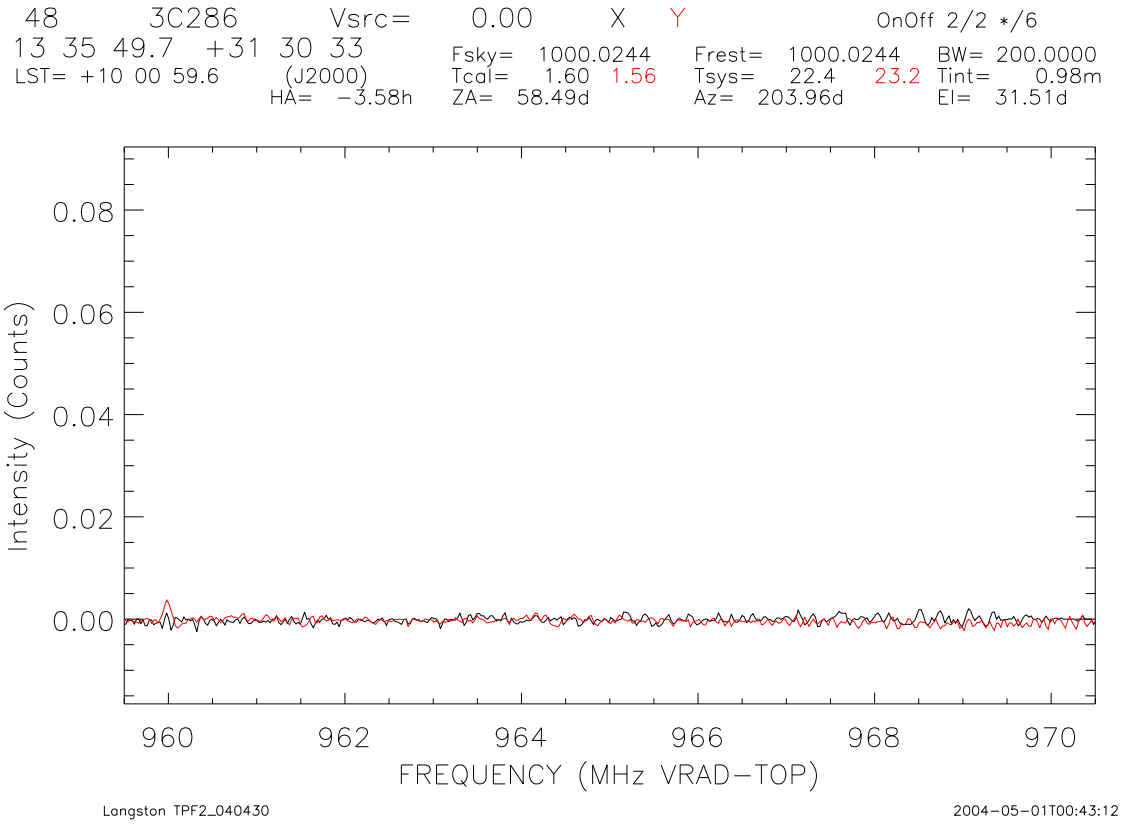

Figure 14: Raw Intensity vs Frequency Plot for dual linear polarization observations.

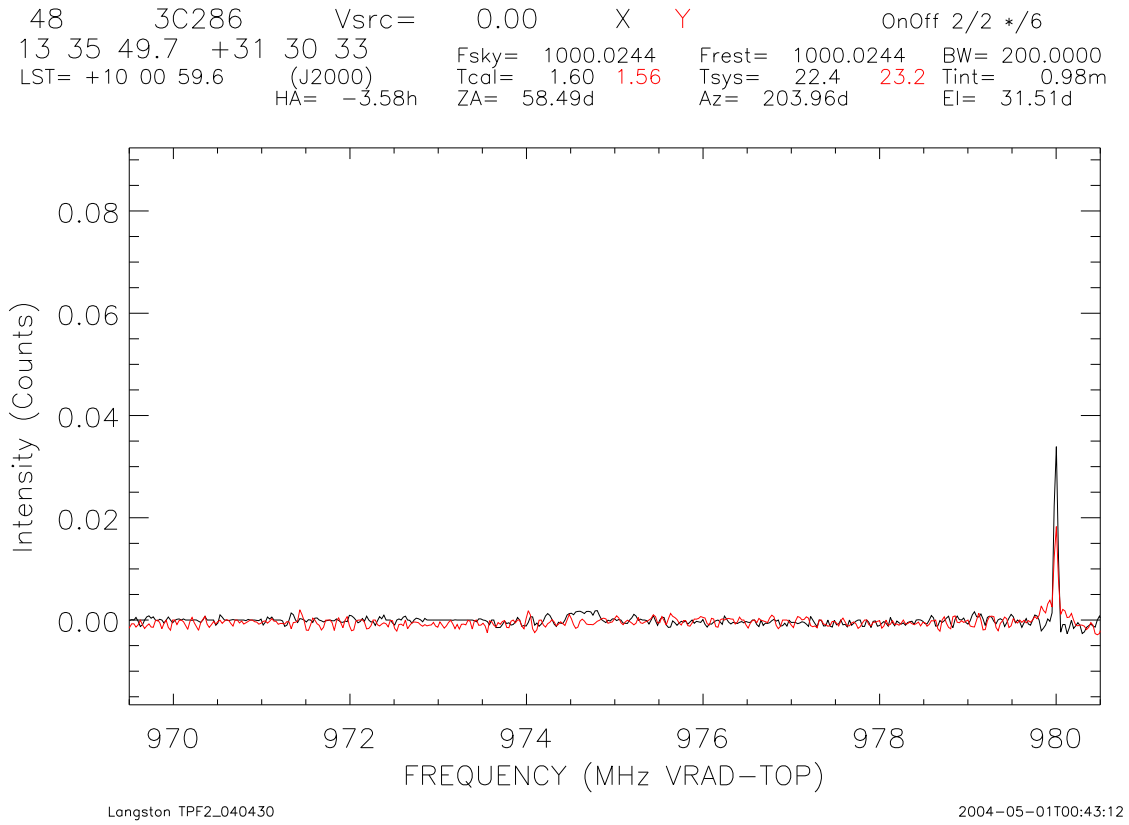

Figure 15: Raw Intensity vs Frequency Plot for dual linear polarization observations.

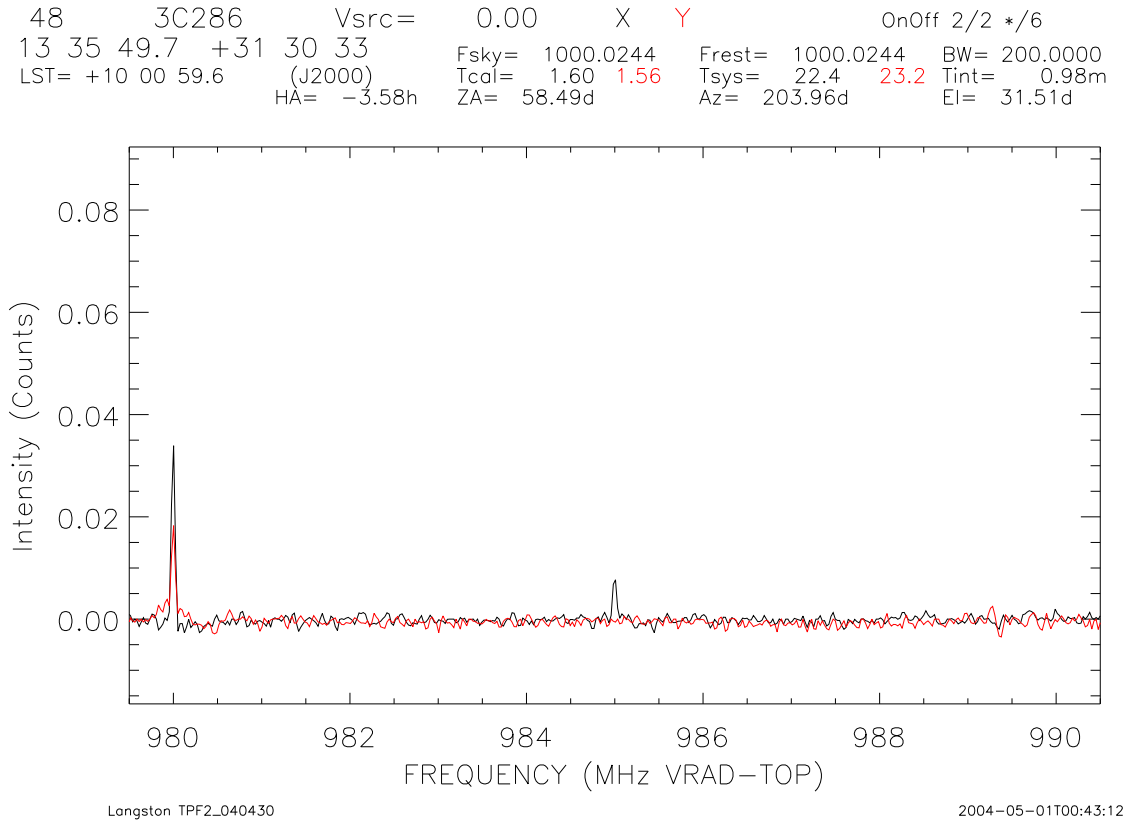

Figure 16: Raw Intensity vs Frequency Plot for dual linear polarization observations.

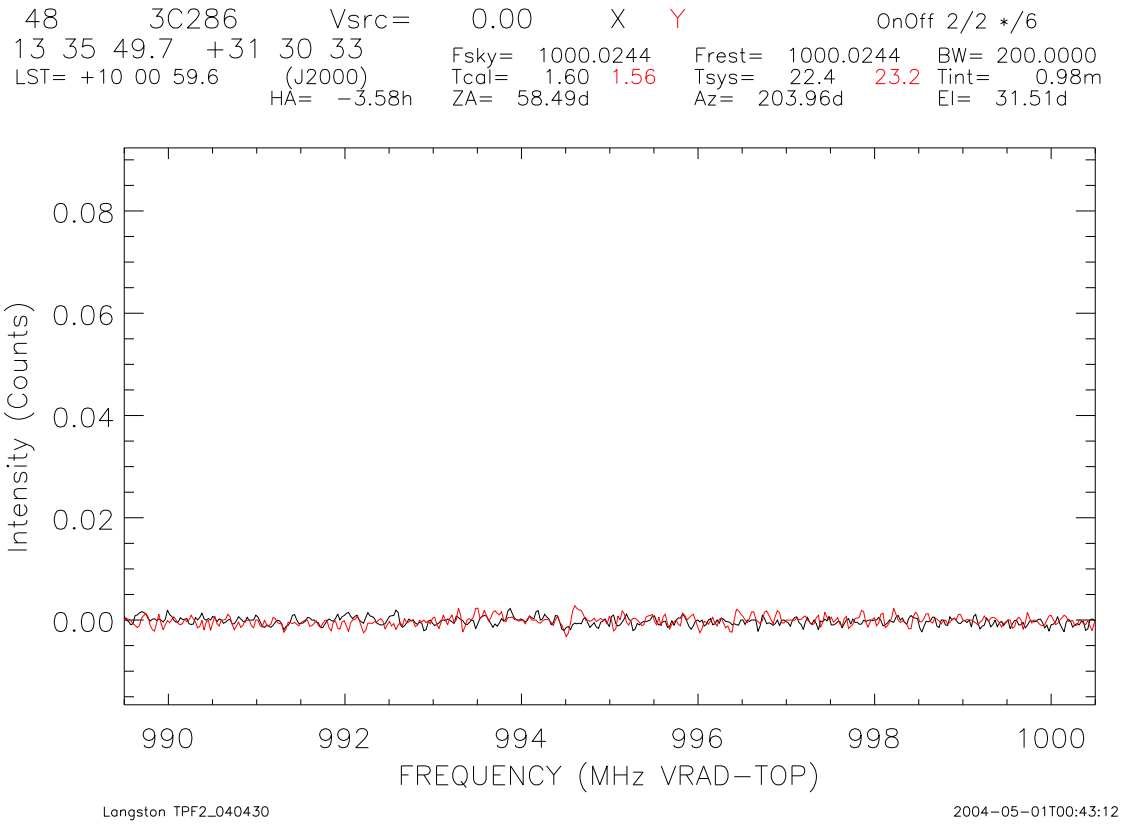

Figure 17: Raw Intensity vs Frequency Plot for dual linear polarization observations.

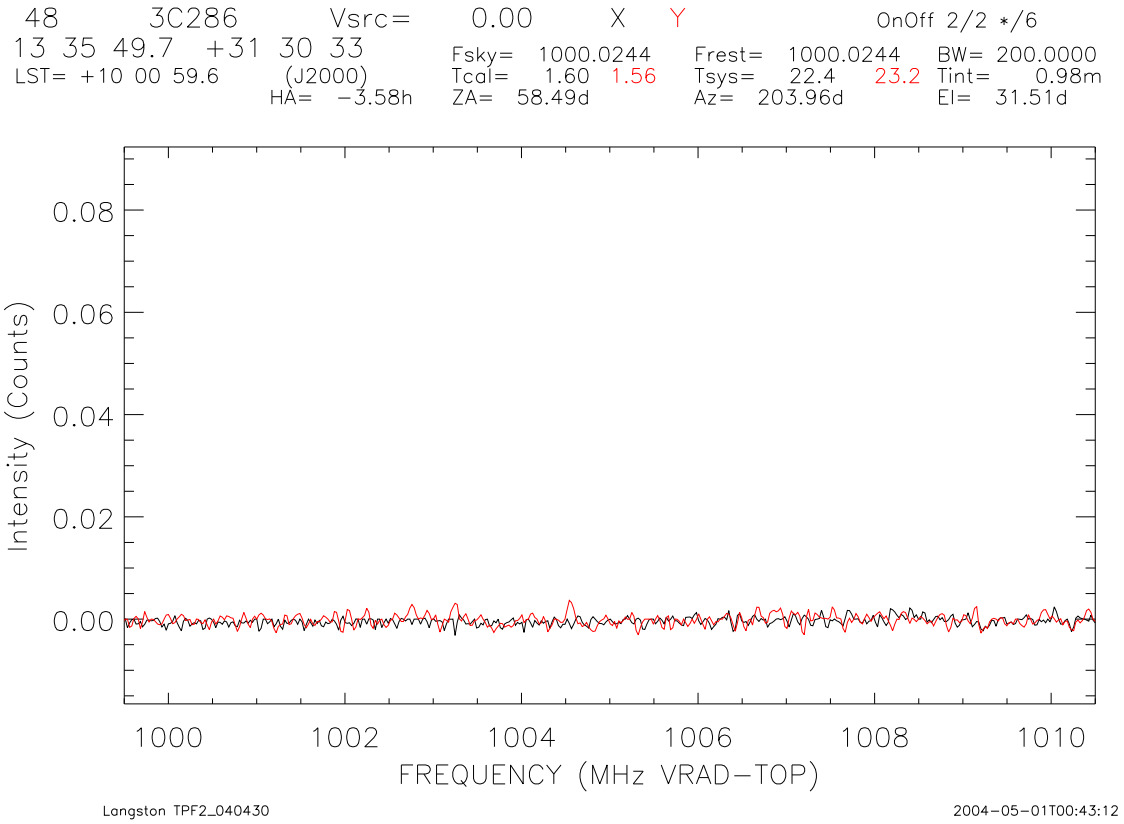

Figure 18: Raw Intensity vs Frequency Plot for dual linear polarization observations.

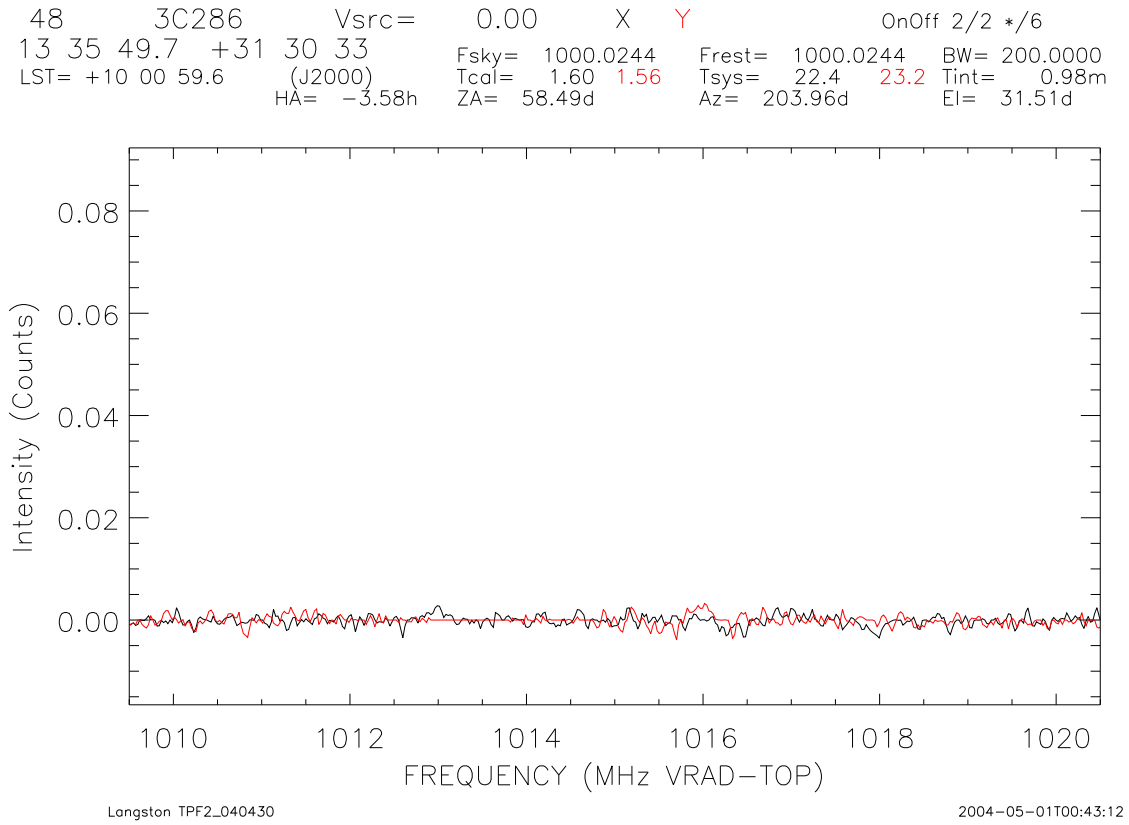

Figure 19: Raw Intensity vs Frequency Plot for dual linear polarization observations.

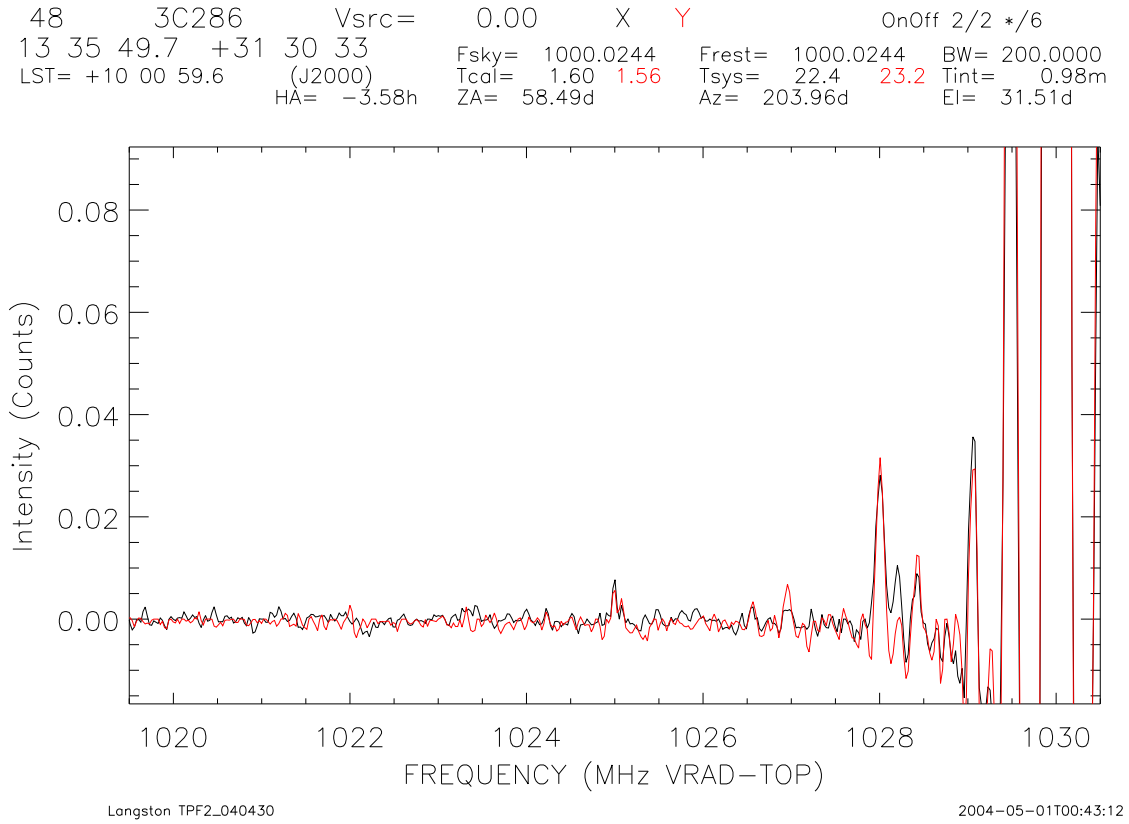

Figure 20: Raw Intensity vs Frequency Plot for dual linear polarization observations.

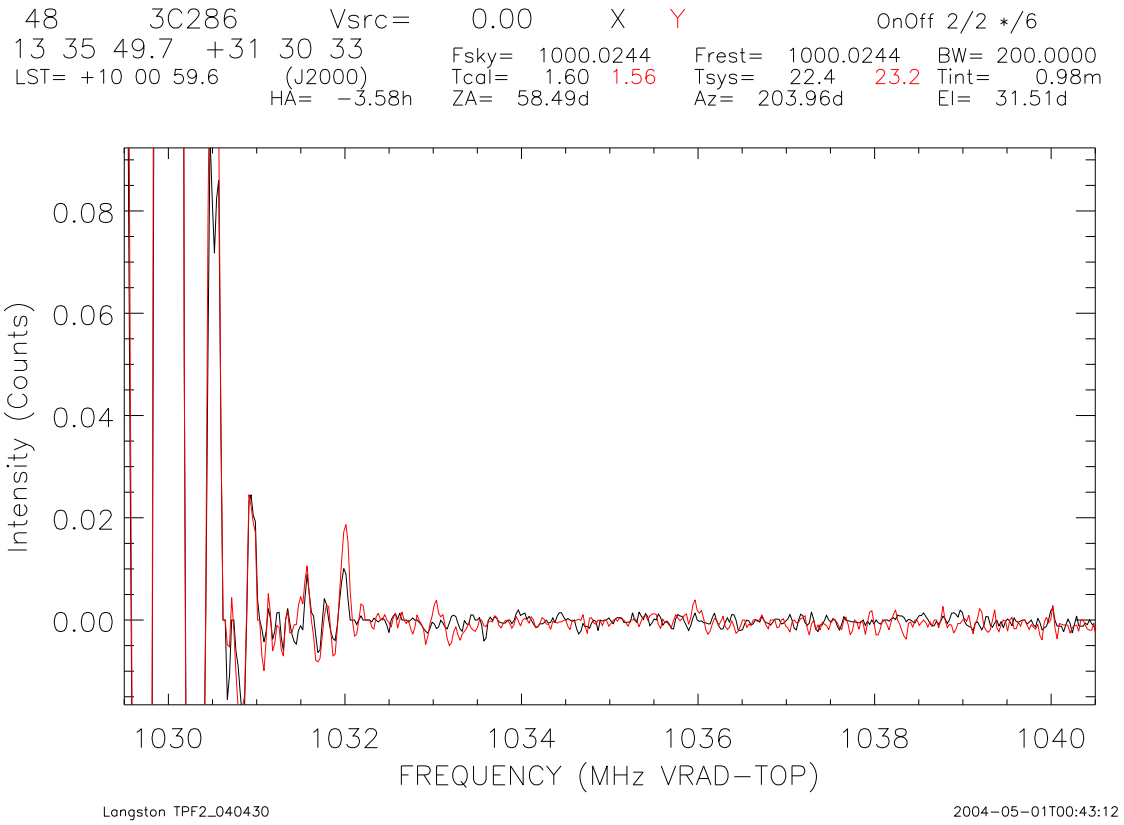

Figure 21: Raw Intensity vs Frequency Plot for dual linear polarization observations.

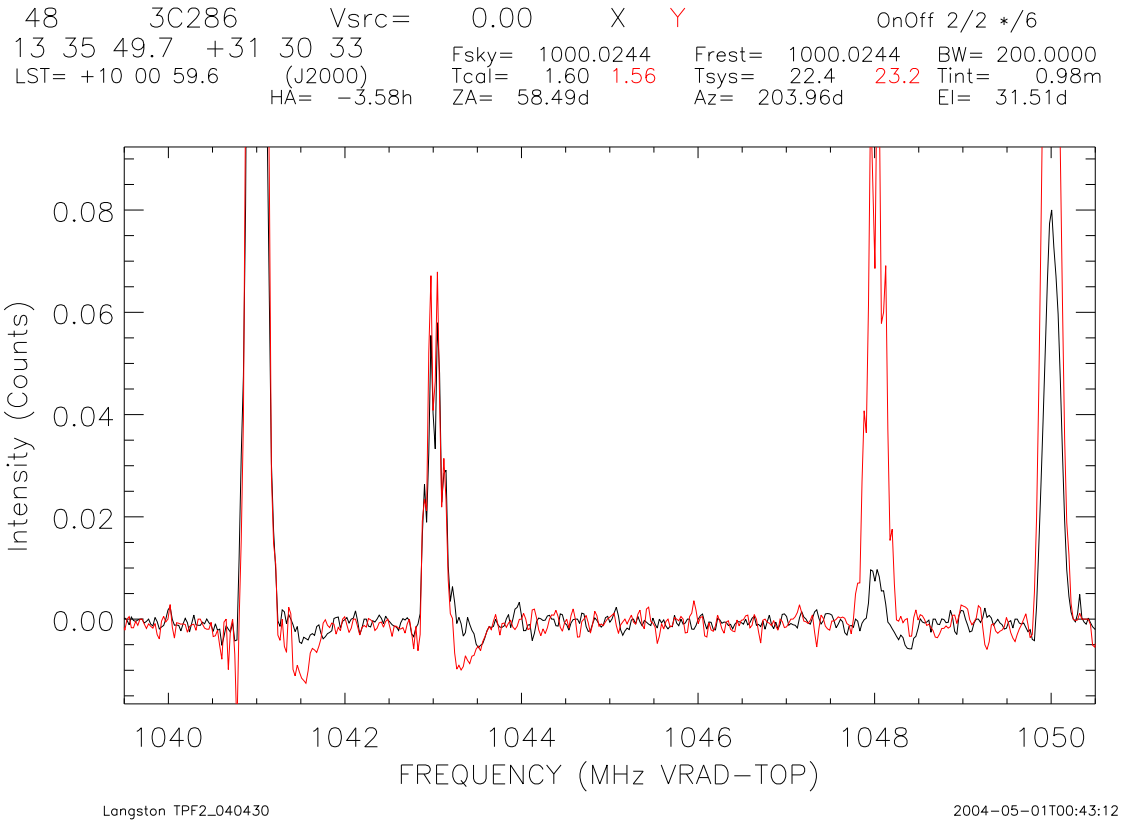

Figure 22: Raw Intensity vs Frequency Plot for dual linear polarization observations.

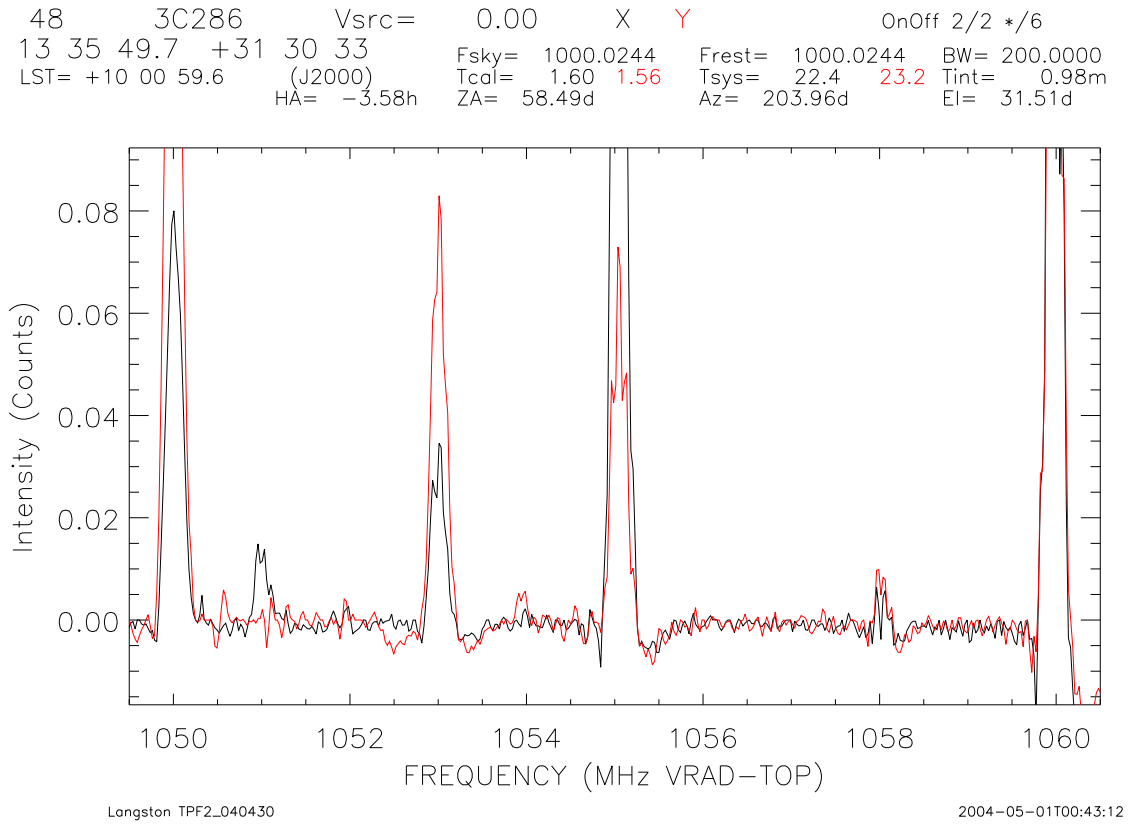

Figure 23: Raw Intensity vs Frequency Plot for dual linear polarization observations.

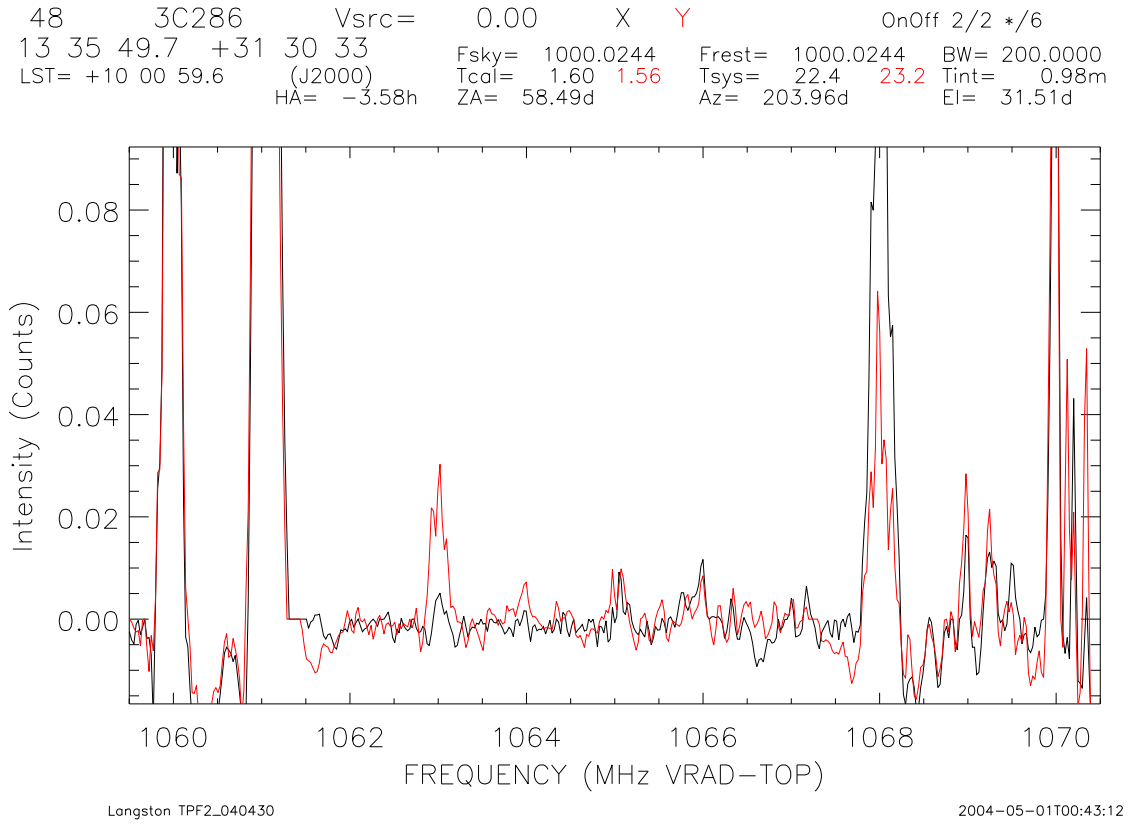

Figure 24: Raw Intensity vs Frequency Plot for dual linear polarization observations.

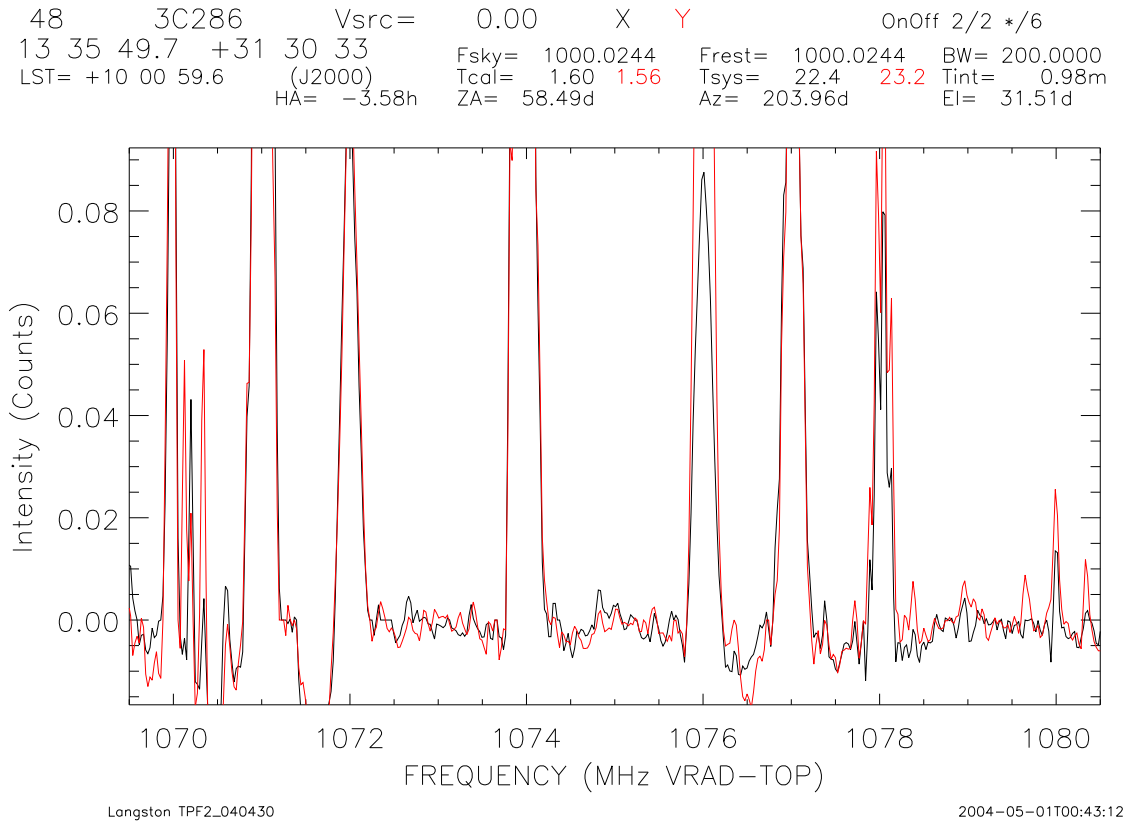

Figure 25: Raw Intensity vs Frequency Plot for dual linear polarization observations.

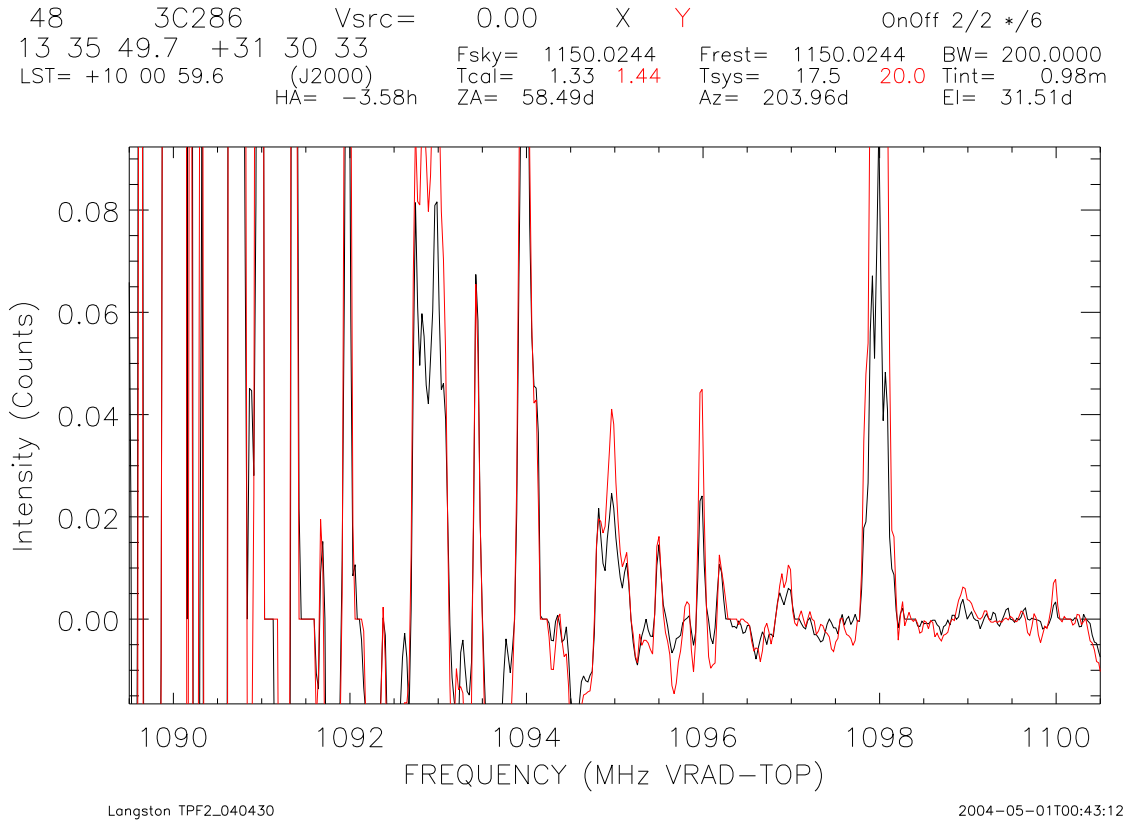

Figure 26: Raw Intensity vs Frequency Plot for dual linear polarization observations.

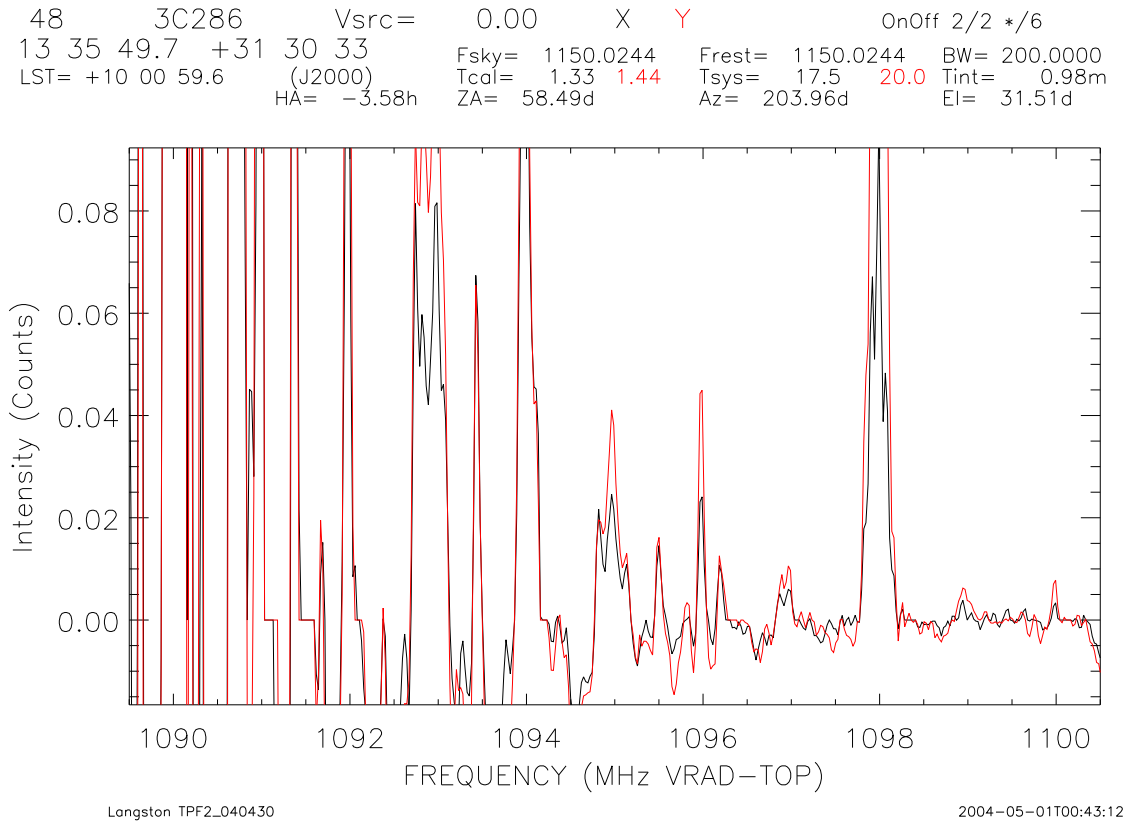

Figure 27: Raw Intensity vs Frequency Plot for dual linear polarization observations.

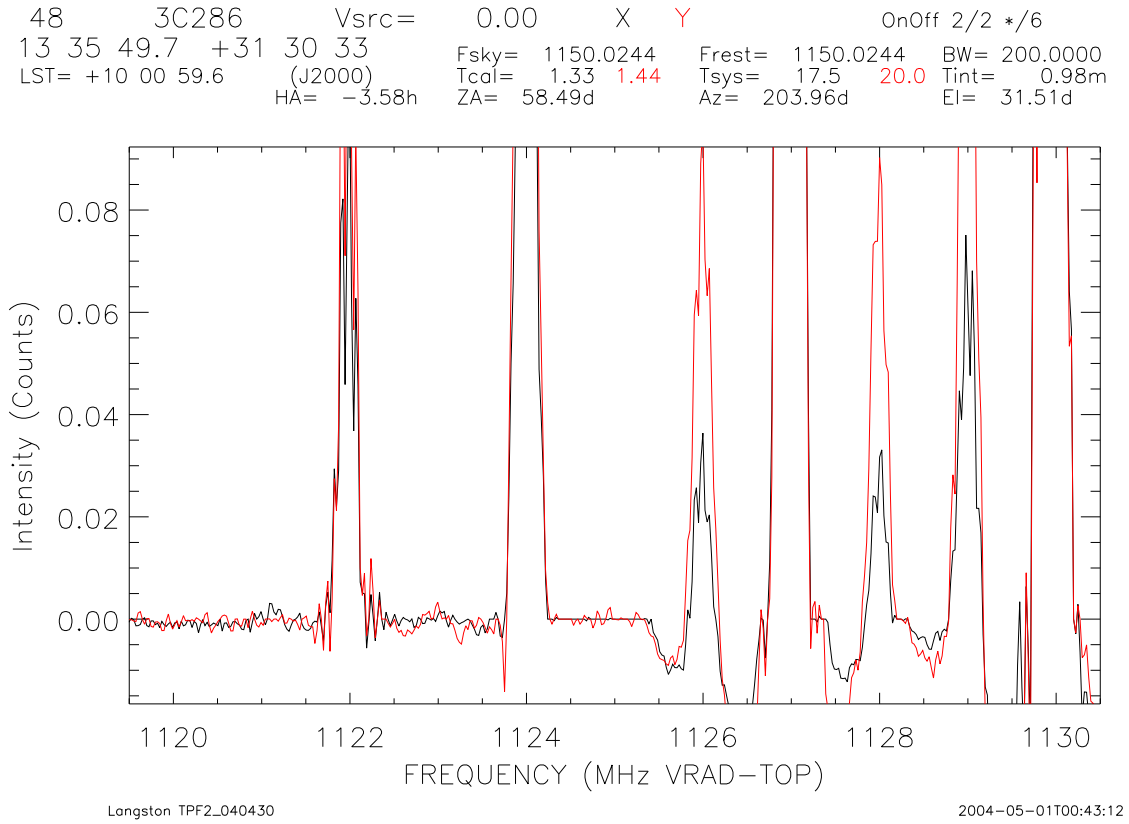

Figure 28: Raw Intensity vs Frequency Plot for dual linear polarization observations.

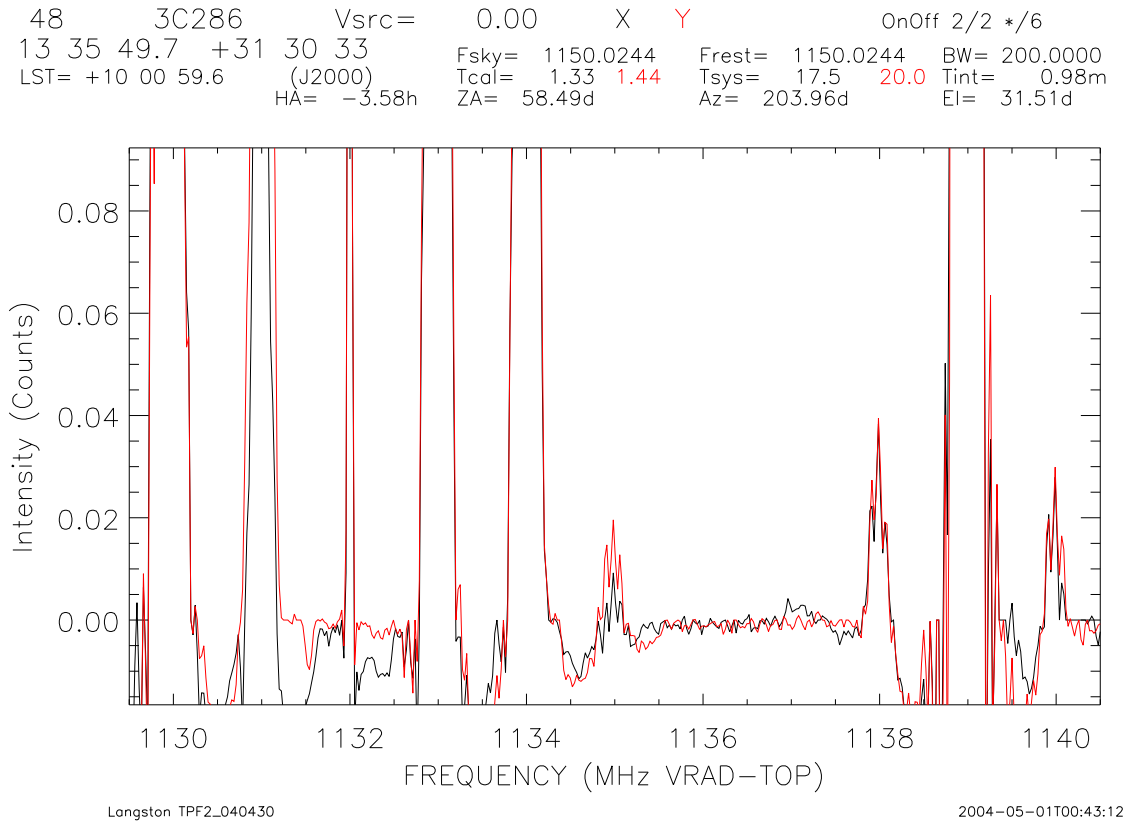

Figure 29: Raw Intensity vs Frequency Plot for dual linear polarization observations.

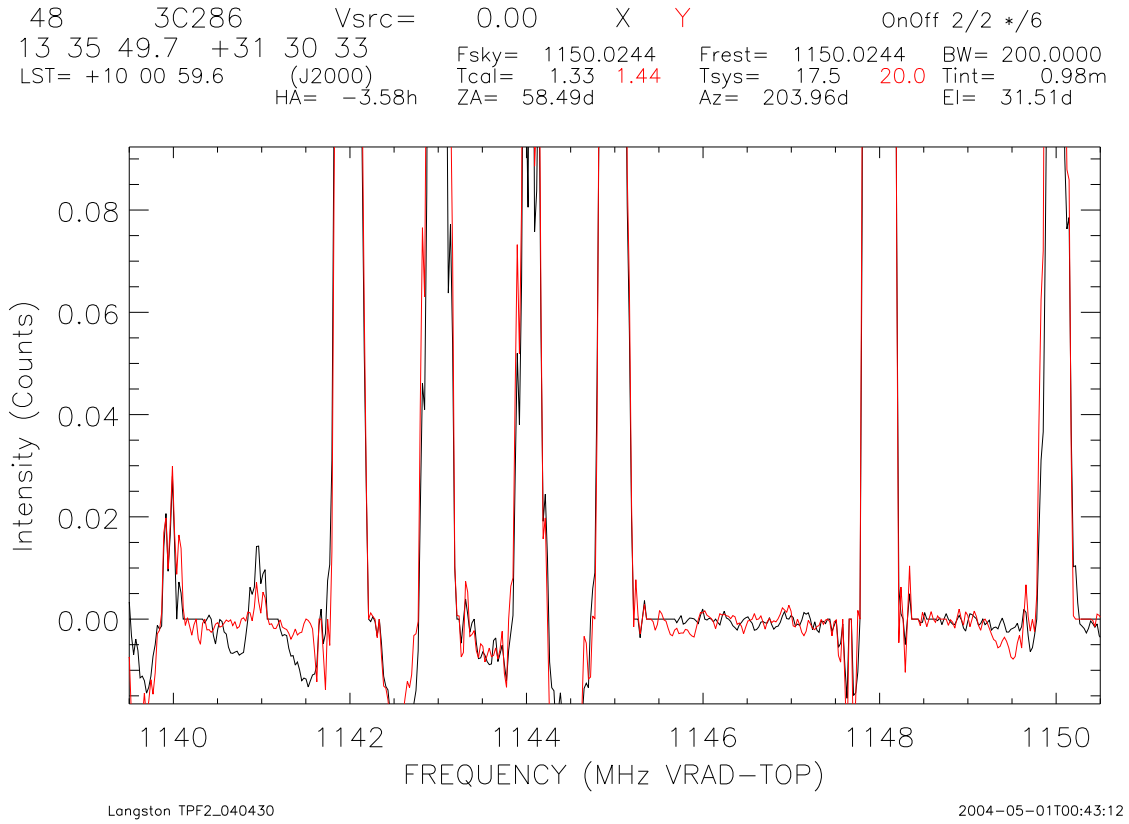

Figure 30: Raw Intensity vs Frequency Plot for dual linear polarization observations.

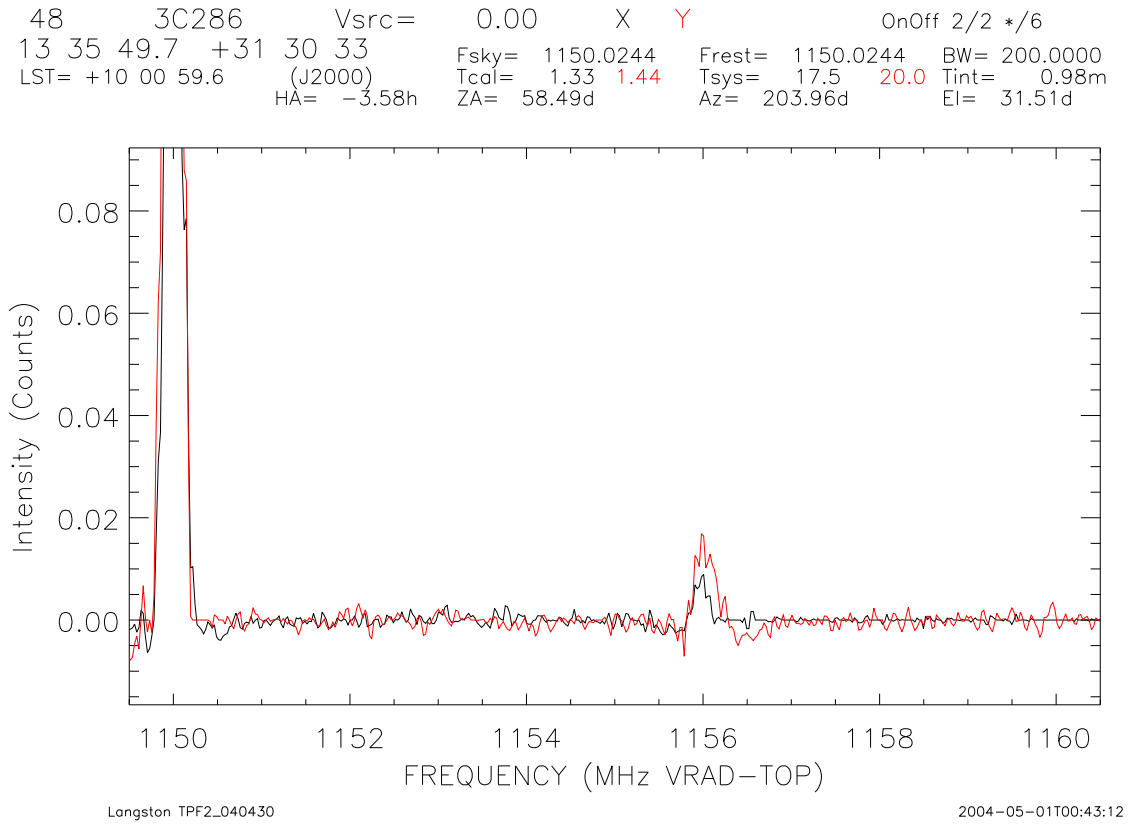

Figure 31: Raw Intensity vs Frequency Plot for dual linear polarization observations.

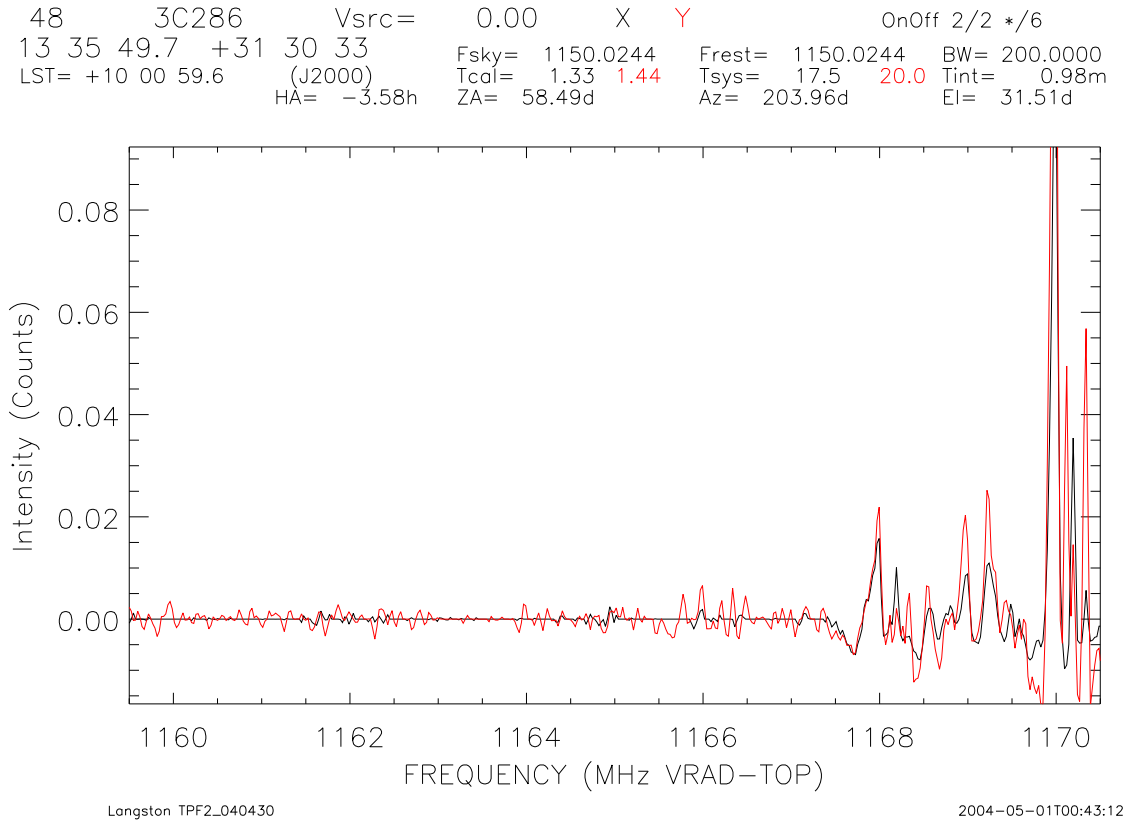

Figure 32: Raw Intensity vs Frequency Plot for dual linear polarization observations.

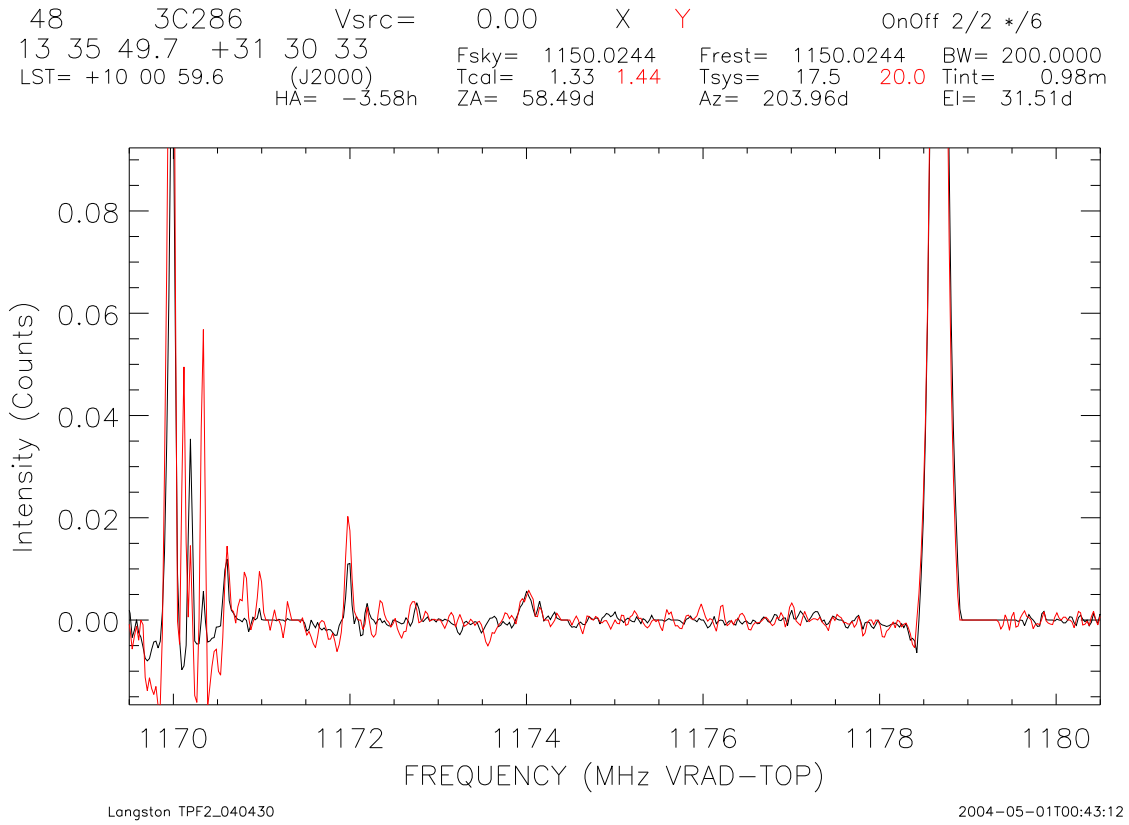

Figure 33: Raw Intensity vs Frequency Plot for dual linear polarization observations.

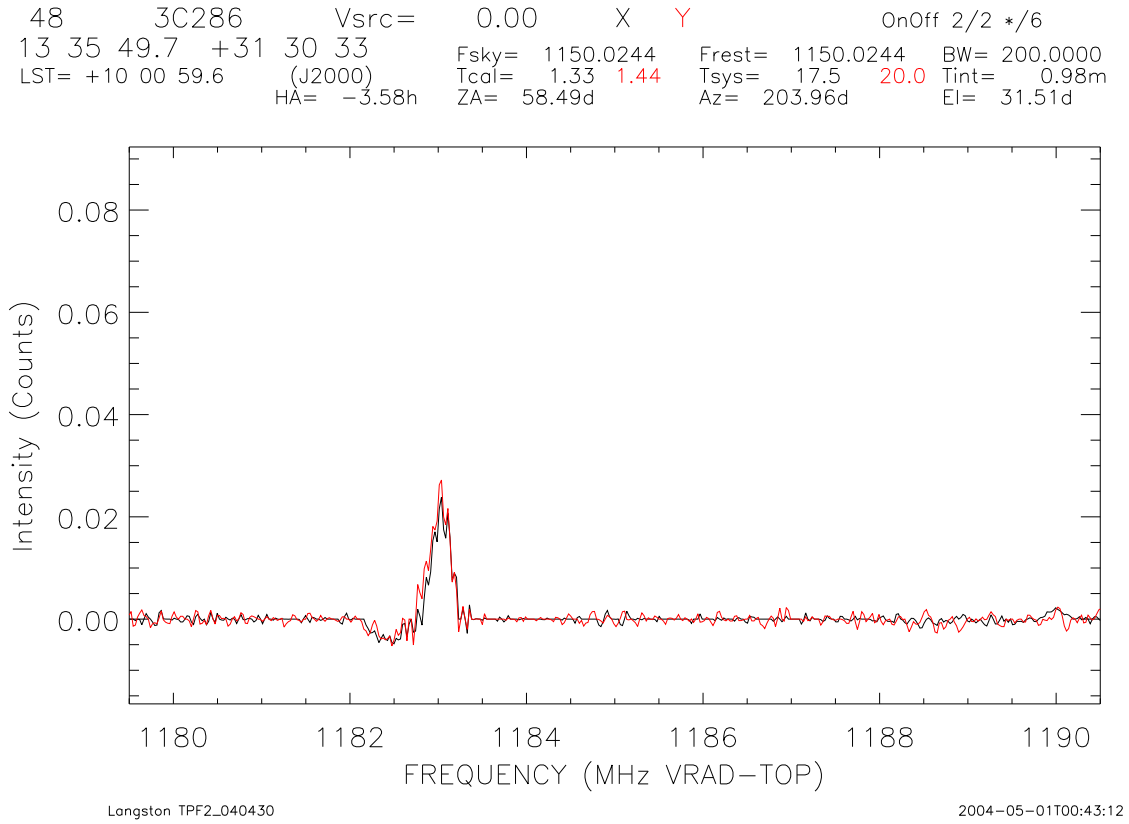

Figure 34: Raw Intensity vs Frequency Plot for dual linear polarization observations.

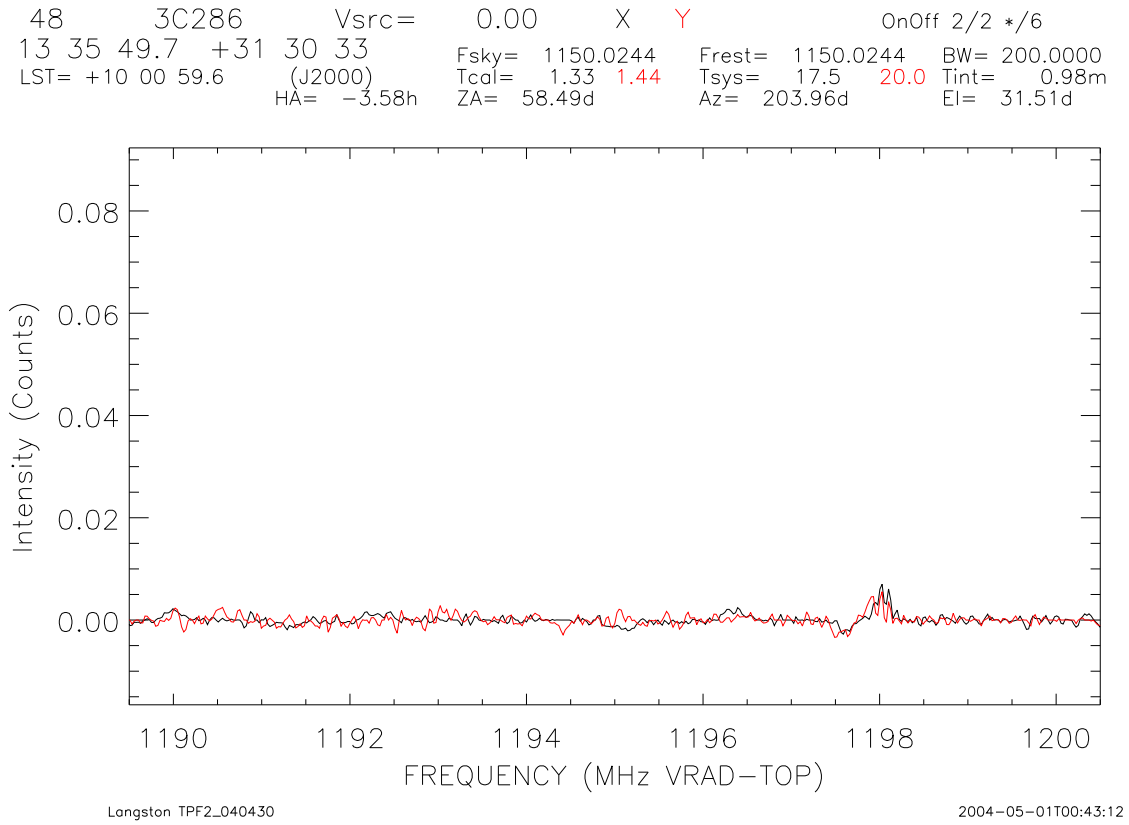

Figure 35: Raw Intensity vs Frequency Plot for dual linear polarization observations.

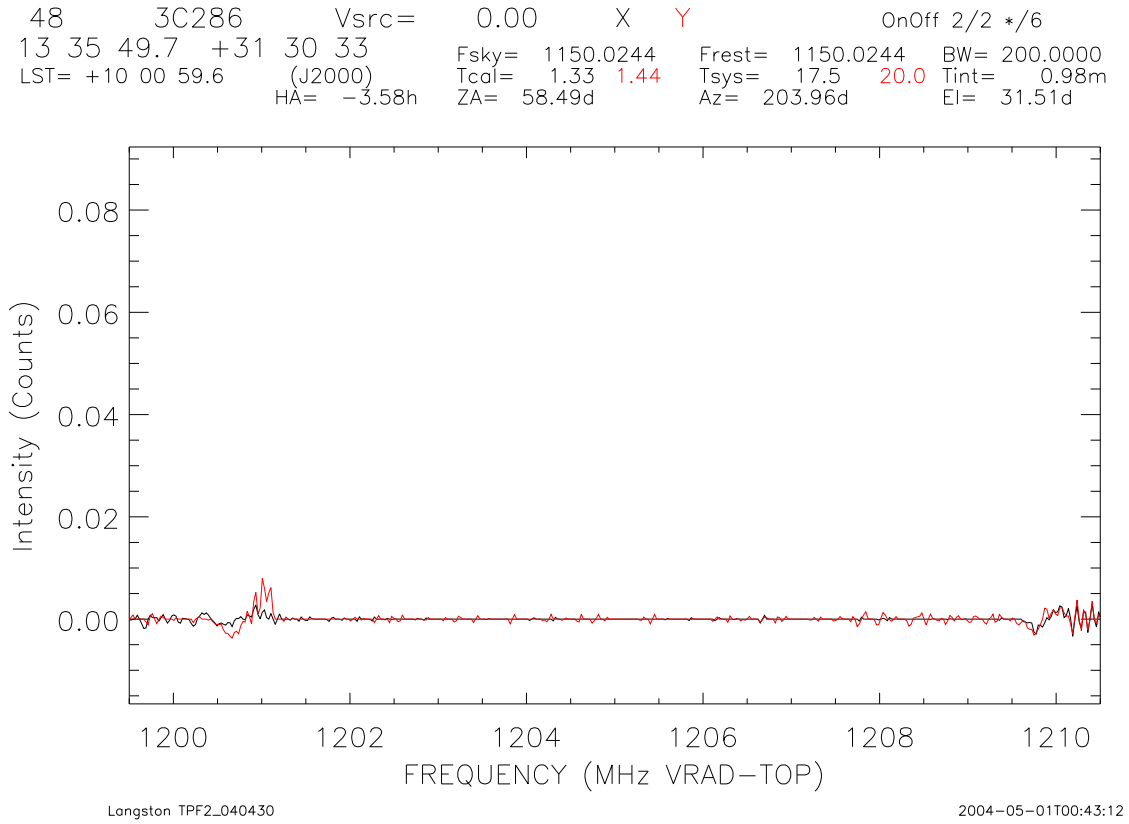

Figure 36: Raw Intensity vs Frequency Plot for dual linear polarization observations.

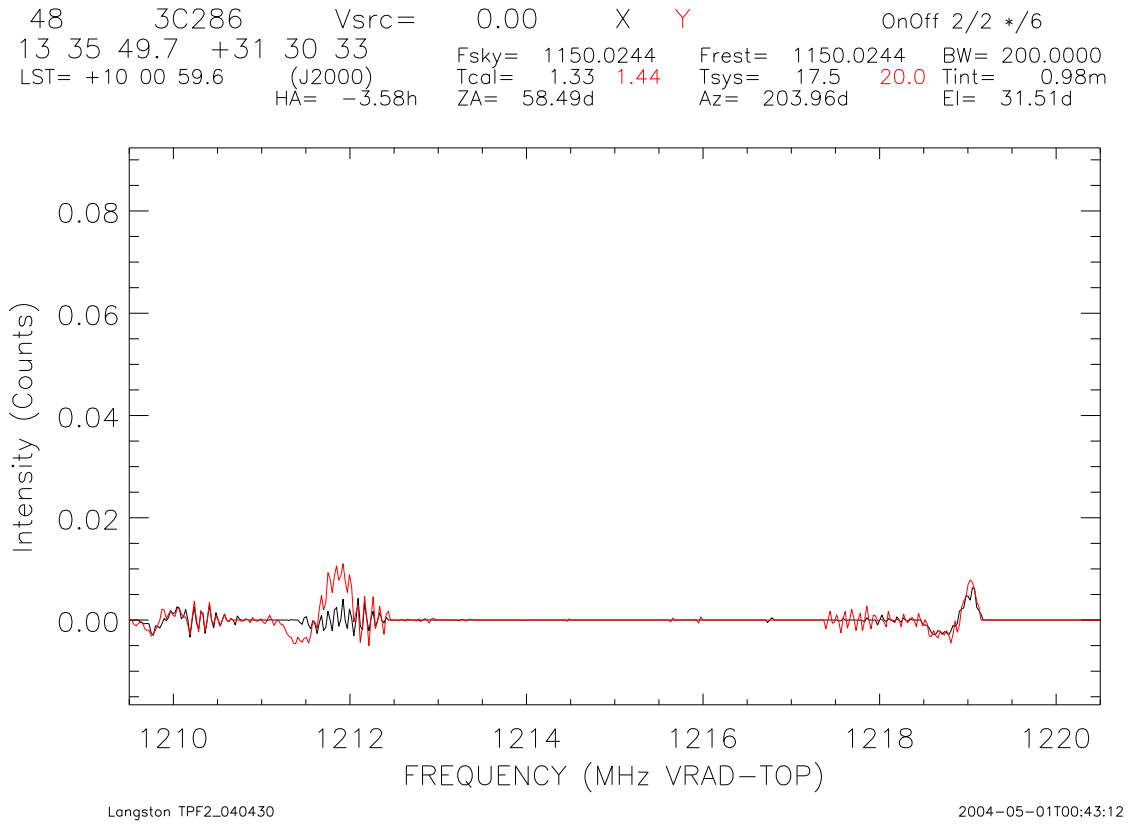

Figure 37: Raw Intensity vs Frequency Plot for dual linear polarization observations.

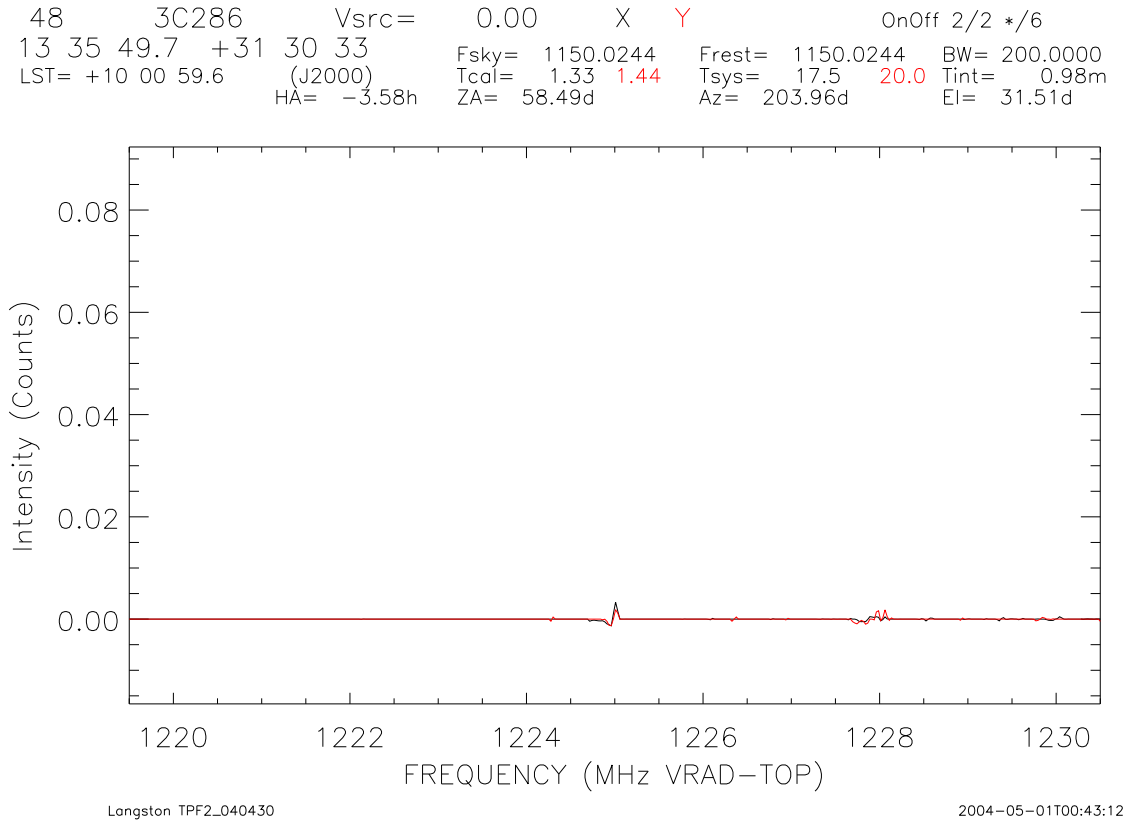

Figure 38: Raw Intensity vs Frequency Plot for dual linear polarization observations.

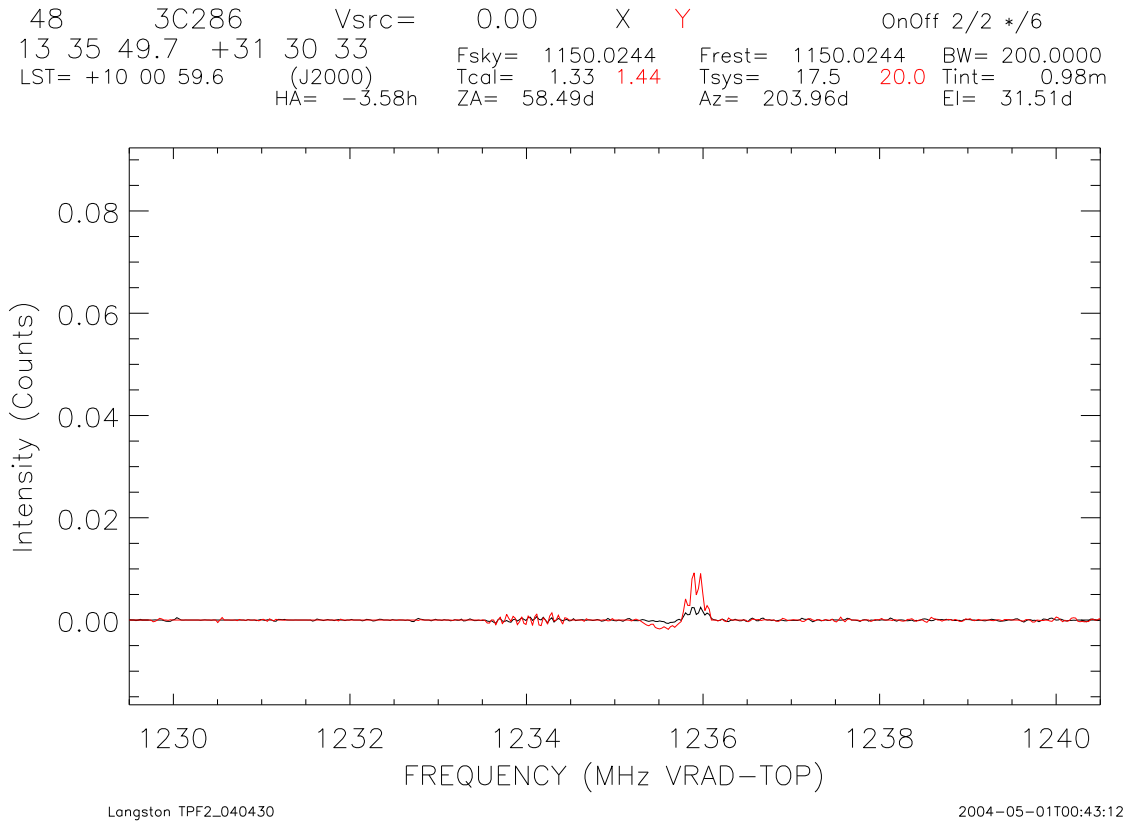

Figure 39: Raw Intensity vs Frequency Plot for dual linear polarization observations.

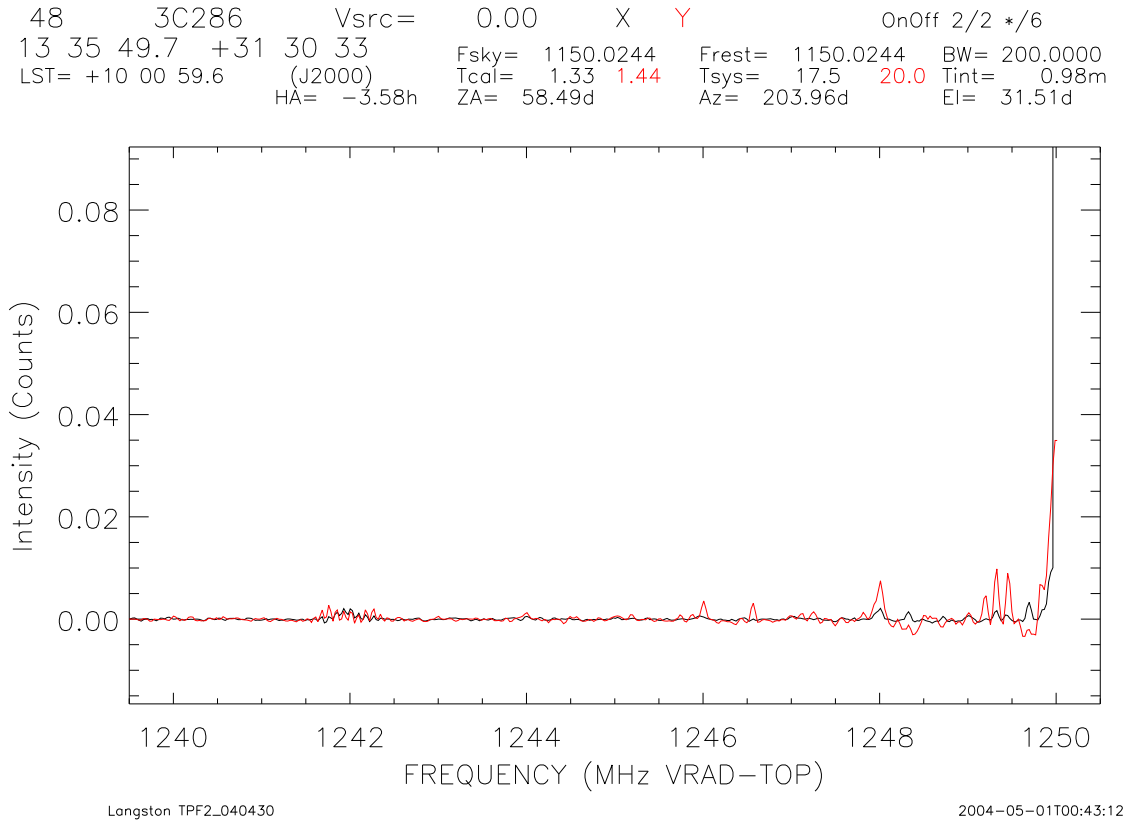

Figure 40: Raw Intensity vs Frequency Plot for dual linear polarization observations.