Further Investigation of L-band Baselines on Continuum Sources
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Setup

The L-band linearly polarized receiver channels X and Y were connected to fibers 1 and 3, respectively. The IF rack filters were set to 2960 to 3040 MHz passband, and the analog filter rack outputs were set to 50 to 100 MHz passband. The spectrometer was set up for 50 MHz bandwidth, 9-level, 2 samplers, 1 quadrant, 8192 channels per IF configuration (1N2-0A-50-9). The signal path connections are shown in Table 1. An integration time of 30 seconds was used for all measurements.

LO1 Offset Check

Figure 1 shows 5-minute on/5-minute off continuum source, 2316+0405, spectra with a 50 MHz bandwidth centered on 1405 MHz. An intensity ripple of about 0.5% p-p amplitude and a period of about 2.3 MHz can be seen in the spectra for both receiver channels. To determine whether this ripple was caused by telescope system components before or after the first mixer, two sets of spectra were recorded, one with a sky center frequency of 1405 MHz (LO1 = 4405 MHz) and the other with a sky center frequency of 1406.2 MHz (LO1 = 4406.2 MHz). If this ripple were due to the 2.4-MHz gain ripple in the fiber modems, its phase would not remain fixed with sky frequency. In Figure 1 the ripple pattern would have shifted by half a wave between the two spectra at different sky center frequencies. It did not, so the ripple was caused by something on the antenna side of the first mixer.

Table 1: IF Rack to DCR Connection Matrix

Rcvr	OR	CM	SF	Sampler
X	1	1	1	0
Y	3	5	5	4

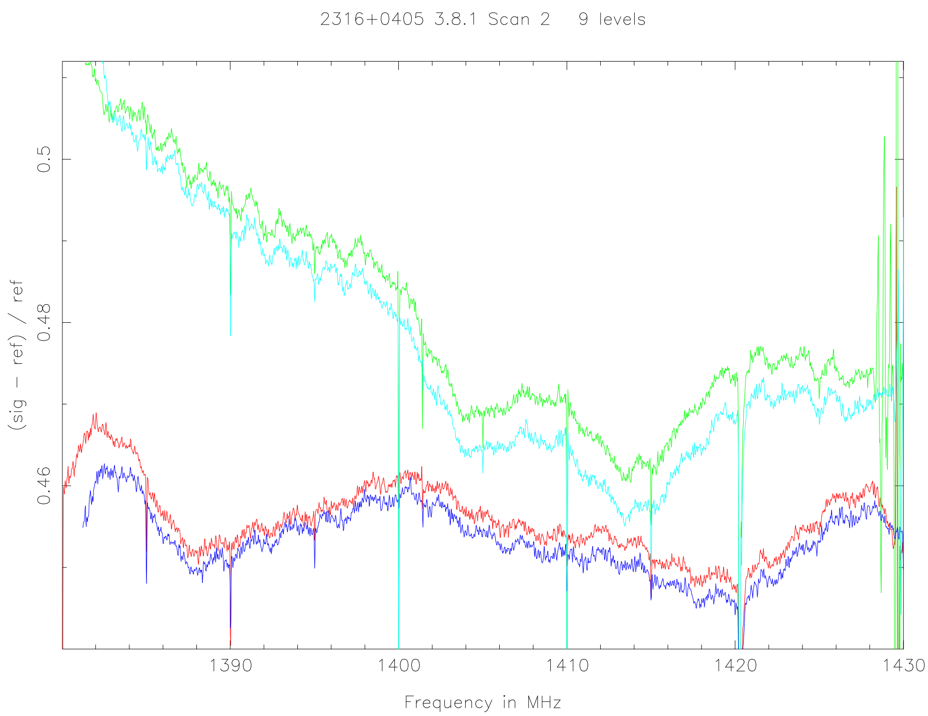

Figure 1: Scans 1-4, LO1 frequency shift test to verify that spectral structure is upstream of first mixer. These spectra are 5-minute (on - off) / off differences on the continuum source 2316+0405 (4.68 Jy). The red and green spectra are receiver channels X and Y, respectively, with a sky center frequency of 1405 MHz. The dark blue and blue-green spectra are channels X and Y with a sky center frequency of 1406.2 MHz. The spectra are smoothed by truncating the ACF at 2048 lags and Hanning convolving the resulting spectra.

Continuum Source Spectra with Subreflector Offset

A 2.3-MHz spectrum ripple could be caused be multipath interference corresponding to a path length difference of 130 meters within the optics of the telescope. This path length is twice the distance between the edges of the subreflector and main reflector nearest the paraboloid axis. To test whether the 2.3-MHz ripple is due to reflections between these two surfaces we moved the subreflector in the +Y direction by 52.5 millimeters ($\lambda/4$) and recorded another on-off pair on 2316+0405. The +Y direction is toward the center of the main reflector. The results are sown in Figure 2. The red and green curves are (on - off) / off spectra with the subreflector in its nominal focus position for receiver channels X and Y, respectively. The dark-blue and blue-green curves are spectral recorded with the subreflector offset. A half-wave shift of the 2.3-MHz ripple is clear in most of the receiver X spectrum and at least part of the receiver Y spectrum. Hence, we can conclude that this ripple is due to a second reflection of a small portion of the continuum source's signal between the main reflector and subreflector. The peak-to-peak amplitude of this baseline ripple is about 0.5% of the continuum source intensity at 1.4 GHz.

Cold Sky Spectra with Subreflector Offset

An interesting spectral baseline phenomenon was discovered by subtracting cold sky spectra recorded with the subreflector at two different Y direction offsets (0 and +52.5 mm). These two measurements were the 'offs' for the continuum source on-offs with the subreflector offsets. The spectra (off1 - off2) / off2 are shown in Figure 3, where off1 is at Y=+55.2mm subreflector offset, and off1 is at zero offset. The red curve is for receiver X, and the green curve is for receiver Y.

Two baseline ripple periods are obvious in Figure 3 with periods of about 9.1 and 1.6 MHz and peak-to-peak amplitudes of about 0.2 and 0.03 Kelvins, respectively. The 1.6-MHz ripple is evident only in receiver channel Y, whose linear polarization is parallel to the plane of symmetry of the telescope. These baseline ripples are apparently due to multipath interference of receiver, spillover, or sky noise involving a reflection from the subreflector. The 9.1-MHz wavelength corresponds to a path delay of 33 meters, which is close to twice the 15.9-meter distance from the feed phase center to the subreflector edge nearest the paraboloid axis. We've seen the 1.6-MHz ripple in frequency-switched spectra on cold sky, again, mainly in channel Y. In the frequency-switched data this ripple moved by half a period with a subreflector Y-offset of only $1/8 - \lambda$, which suggests that two subreflector reflections are involved. The period of 1.6-MHz corresponds to a path length difference of about 190 meters, which is roughly twice the distance from the feed phase center to the subreflector to the center to the main reflector.

Figure 4 shows a Fourier transform of the spectra shown in Figure 3. In this figure the horizontal axis units correspond to multipath interference path length differences of 6 meters. The peak at 5 units (30 meters) corresponds to

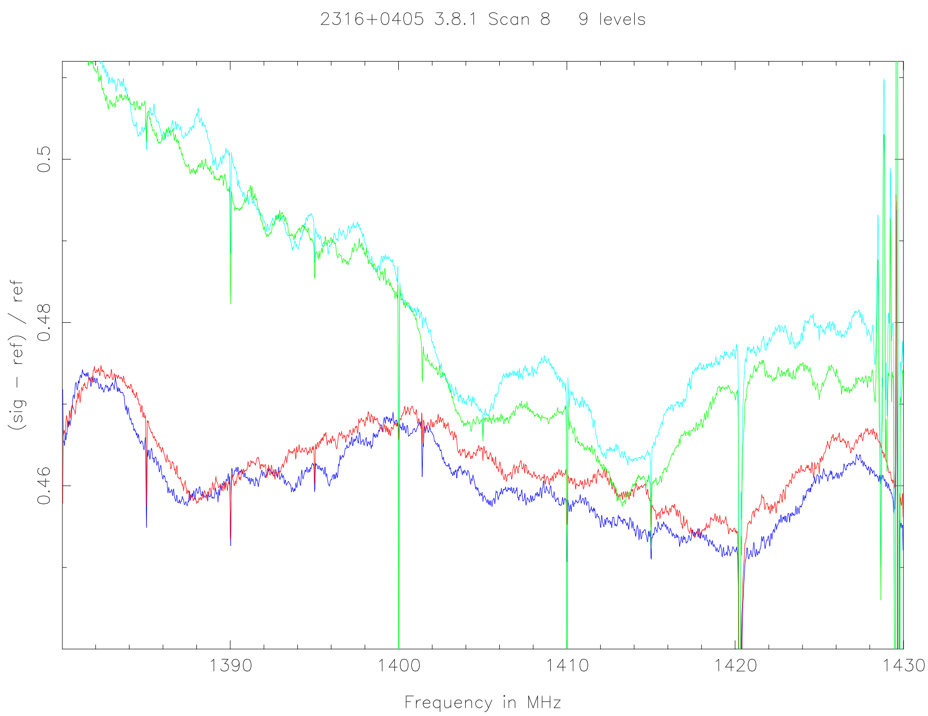

Figure 2: Scan 5-12, continuum source 2316+0405 spectra at two subreflector Y-focus positions. The red and green curves are for receiver channels X and Y, respectively, with the subreflector in its nominal focus position. The dark-blue and blue-green curves are for receiver channels X and Y, with the subreflector offset by 52.5 mm (1/4-wavelength) from its nominal focus position. The spectra are smoothed by truncating the ACF at 2048 lags and Hanning convolving the resulting spectra.

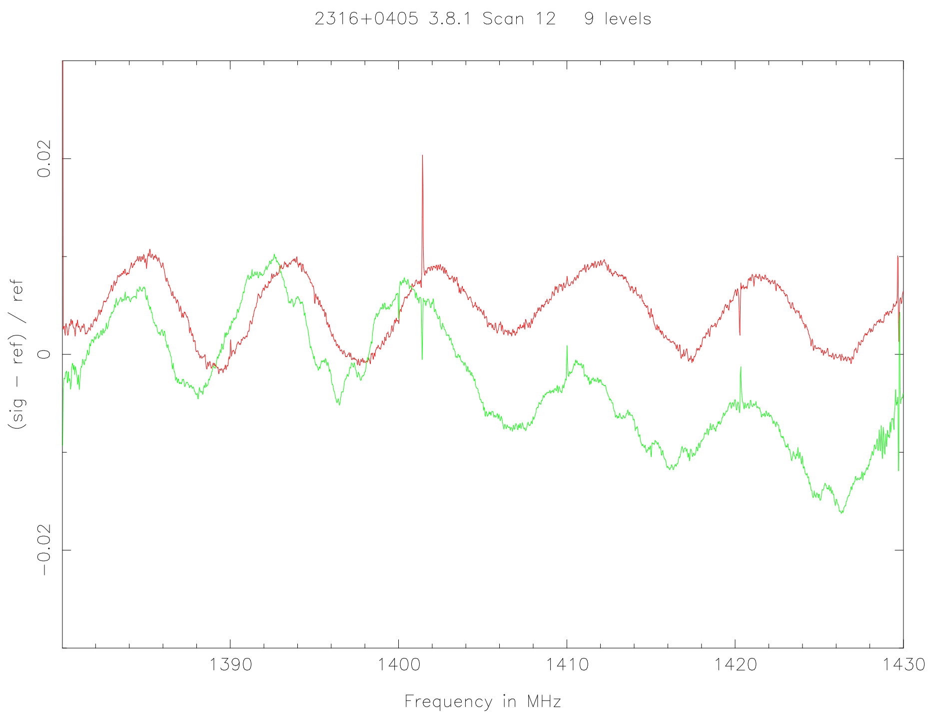

Figure 3: Scans 6, 8, 10, and 12, cold sky spectra for 5-minute scans 10 and 12 at nominal subreflector focus were averaged and subtracted from the average of 5-minute scans 6 and 8 at a Y-focus offset of 52.5 mm (1/4-wavelength). The red curve is receiver channel X, and the green curve is channel Y. The spectra are smoothed by truncating the ACF at 2048 lags and Hanning convolving the resulting spectra.

the 9.1-MHz ripple period. The 190-meter peak (32 units) is quite broad ranging from about 30 to 37 units (180 to 222 meters), which leads us to suspect that it is due to reflections from the circumferential panel gaps in the surface whose distance from the feed phase center varies from 81 to 126 meters (half of 162 to 252 meters). Reflections from the gaps near the center of this distance range are expected to be the strongest since they are more heavily illuminated by the feed pattern. The fact that this baseline ripple is strongest in channel Y fits the expectation that the gaps should scatter most strongly in linear polarization perpendicular to their circumferential direction. A double reflection from the subreflector also fits this picture. The $\lambda/4$ subreflector offset used in the data of Figures 3 and 4 will tend to suppress the 1.6-MHz ripple because it will be shifted by nearly a full period between the 'off1' and 'off2' spectra. A new measurement with a $\lambda/8$ subreflector offset as well as an offset in the orthogonal direction is called for to verify the source of this ripple. We also want to investigate whether the noise experiencing multipath interference is primarily atmospheric, receiver, or spillover noise by measuring this effect at different zenith distances to change the atmospheric component.

Composite Continuum Source Spectra

A major component of the frequency-dependent Tsource/Tsys spectrum of a continuum radio source appears not to be due to multipath interference, but it is due to system components ahead of the first mixer. To get a broader picture of this frequency-dependence in the L-band receiver a composite 200-MHz wide spectrum was assembled for each receiver by measuring 50-MHz spectra at 30-MHz intervals of the first LO frequency. The results are shown in Figure 5. These spectra have been corrected for the smooth variation of the continuum source flux density across the frequency range. Note that the frequency dependence of the quantity plotted in this figure can reside in either the (on - off) numerator, which is a gain modulation of the continuum source power, or in the denominator, which is a product of the system noise and the gain of the system. The system gain following the major sources of system noise will cancel in the (on - off) / off quotient, but variations in system noise across the band will not.

Continuum Source Spectra Ratios

Regardless of the cause of the frequency dependence of the (on - off) / off spectra for continuum radio sources, we expect the spectra to scale with source flux density. To test this we observed two continuum source which are roughly a factor of two different in intensity, 2316+0405 (S=4.68 Jy @ 1.4 GHz) and 0054-0333 (S=2.21 Jy @ 1.4 GHz). The spectrum for 0054-0333 is shown in Figure 6 and the ratio of the 0054-0333 and 2316+0405 (on - off) / off spectra are shown in Figure 7. The two sources were measured at nearly the same telescope elevation. The ratio spectra are nearly flat, but not sufficiently so to

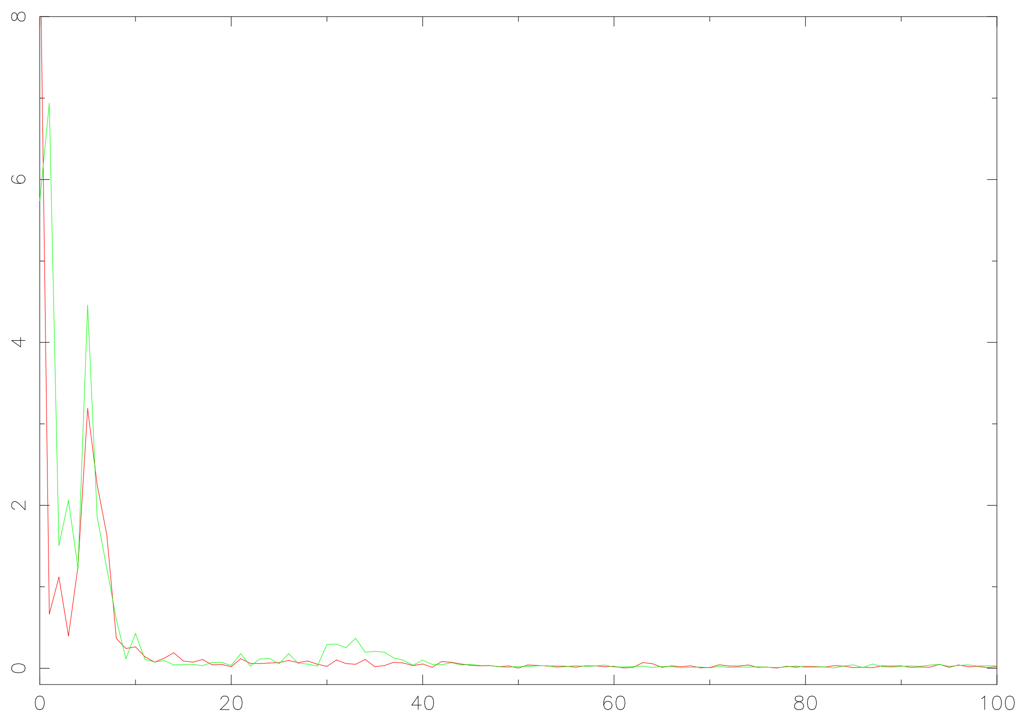

Figure 4: Scans 6, 8, 10, and 12, FFT of the spectrum differences shown in Figure 3. The horizontal axis is inversely proportional to ripple period, where one unit equals 1/50 MHz corresponding to a multipath interference path length difference of 6 meters. The vertical scale is proportional to spectral power. The red curve is for receiver channel X, and the green the green curve is for channel Y.

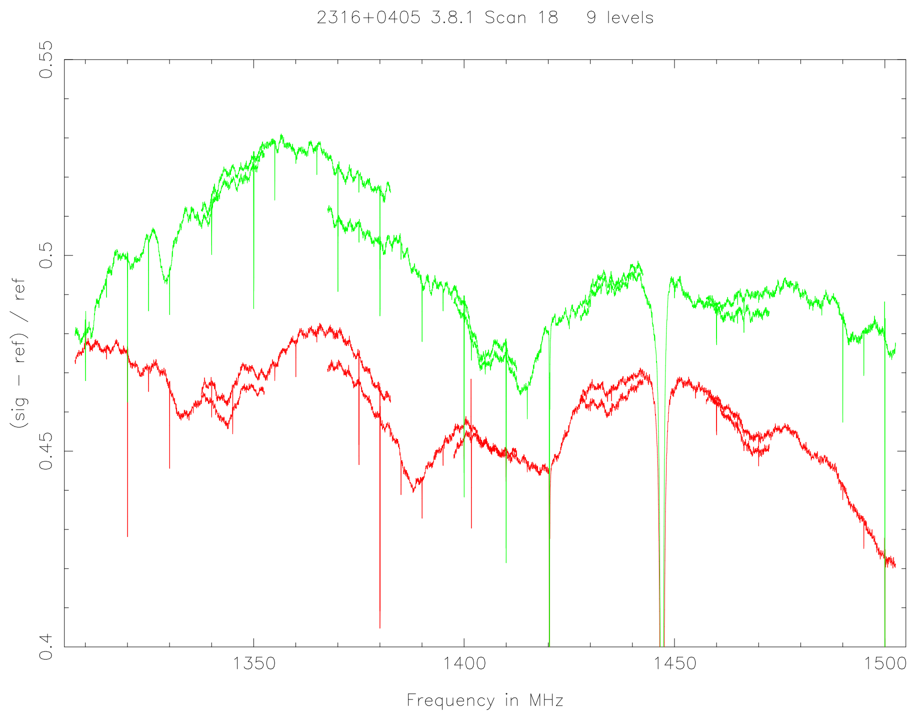

Figure 5: Scans 17-28, composite Tsource/Tsys spectra for the continuum radio source 2316+0405 (S=4.68 Jy @ 1.4 GHz). The red curves are for receiver channel X and the green curves are for channel Y. The central 90% of each 50 MHz spectrum is plotted. The spectra are corrected for a source spectral index of -1.006 derived from the NVSS flux densities at 1.4 and 5 GHz. The narrow negative spikes are interference. The spectra are smoothed by truncating the ACF at 2048 lags and Hanning convolving the resulting spectra.

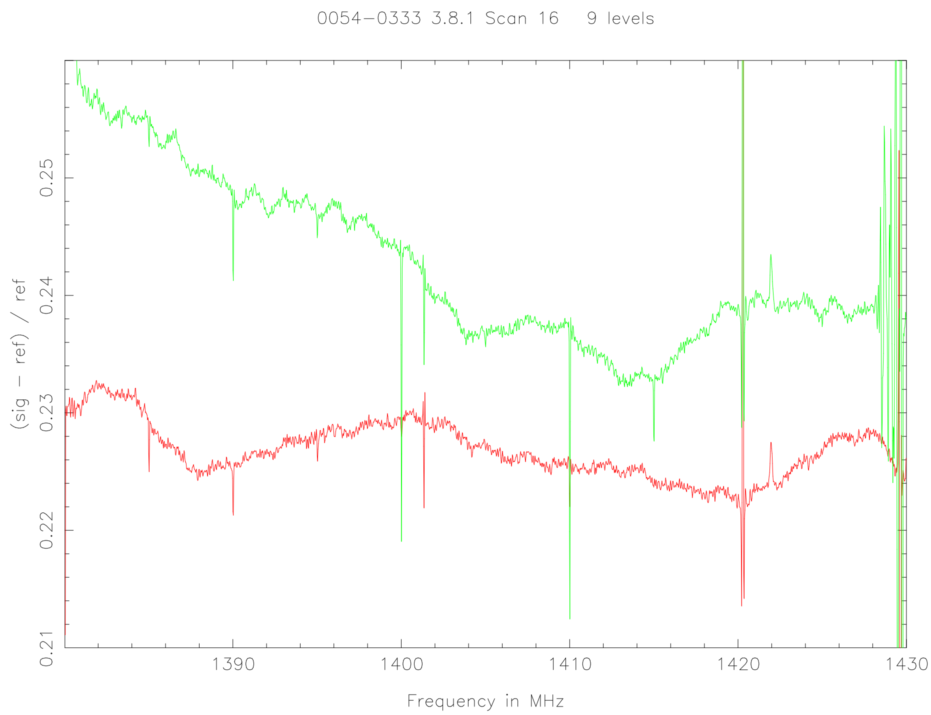

Figure 6: Scans 13-16, Tsource/Tsys spectra for the continuum radio source 0054-0333 (S=2.21 Jy @ 1.4 GHz). The red curve is for receiver channel X and the green curve is for channel Y. The spectra are smoothed by truncating the ACF at 2048 lags and Hanning convolving the resulting spectra.

acheive the ideal signal-to-noise limit of the spectrometer. This needs further investigation.

To test the stability of the continuum spectrum we can look at the ratio of the (on - off) / off spectra for 2316+0405 taken roughly ten minutes and one hour apart. Figure 8 shows that, oddly enough, the spectra taken ten minutes apart agree no better than the ones measured an hour apart. In some respects the ten-minute ratio is rougher than the one-hour ratio. Again, more investigation is required.

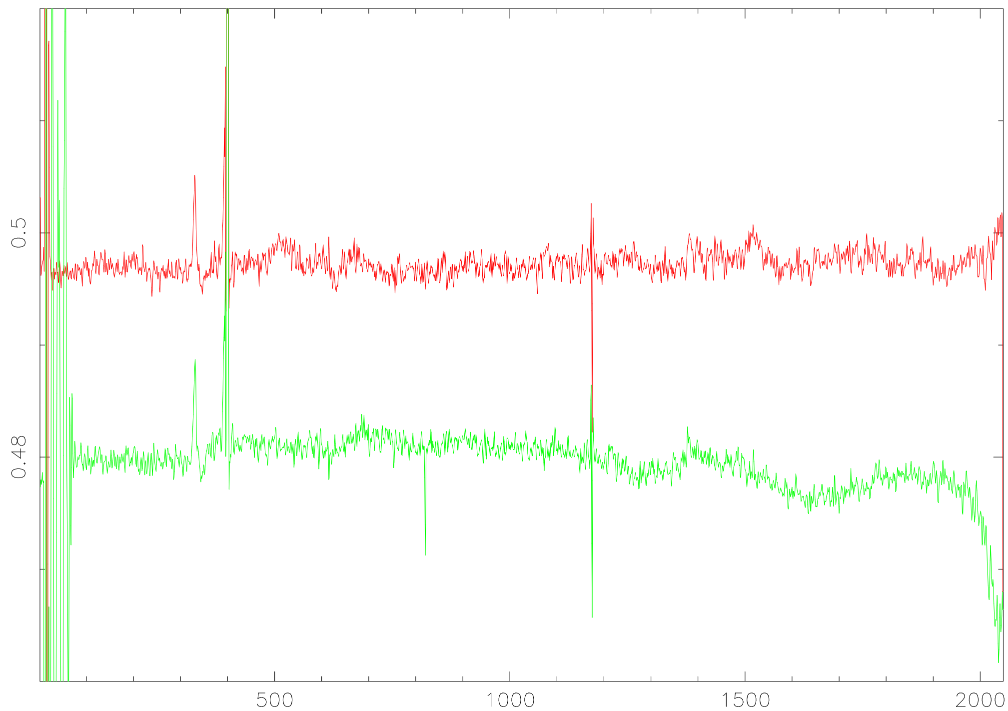

Figure 7: Scans 9-16, ratio of Tsource/Tsys spectra for the two continuum radio sources 2316+0405 and 0054-0333. The spectra used in this ratio are shown in Figures 2 (red and green curves) and 6. The red curve is for receiver channel X and the green curve is for channel Y. The spectra are smoothed by truncating the ACF at 2048 lags and Hanning convolving the resulting spectra.

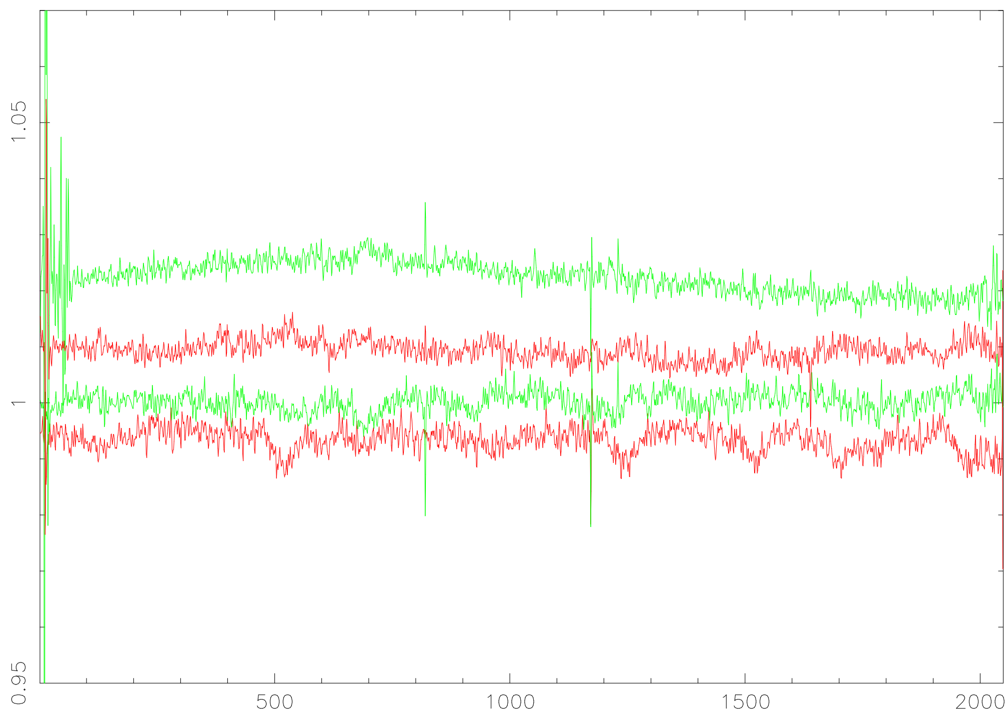

Figure 8: Scans 1, 2, and 9-12, ratio of Tsource/Tsys spectra for the two measurements of 2316+0405 taken about ten minutes and one hour apart. The red curves are for receiver channel X and the green curves are for channel Y. The bottom two spectra are ratios of measurements taken ten minutes apart, and the top two spectra are for measurements taken one hour apart (displaced by +0.01 to separate the plots). The spectra are smoothed by truncating the ACF at 2048 lags and Hanning convolving the resulting spectra.