North American ALMA Science Center

Closure Errors with ALMA

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ABSTRACT

Here I report on the analysis of the magnitude of phase closure errors, and to a lesser extent amplitude errors, in ALMA observations with and without LO offsetting. Data were taken in Bands 3, 6, 7 and 9, though the Band 7 data are of low quality and are not considered here. Without LO offsetting, phase closure errors in bands 3 and 6 are roughly 0.5 degrees (median offset from 0 degrees and the rms about that median). With LO offsetting, the median offset from 0 degrees is improved by roughly a factor of 3 and the rms about that median is reduced by a factor of ~15. The reduction in phase closure errors holds for both dual and full polarization data sets. The Band 9 data set (without LO offsetting) does not show obvious phase closure errors but the signal to noise is not sufficient to make a precise estimate of phase closure problems.

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Abstract

Here I report on the analysis of the magnitude of phase closure errors, and to a lesser extent amplitude errors, in ALMA observations with and without LO offsetting. Data were taken in Bands 3, 6, 7 and 9, though the Band 7 data are of low quality and are not considered here. Without LO offsetting, phase closure errors in bands 3 and 6 are roughly 0.5 degrees (median offset from 0 degrees and the rms about that median). With LO offsetting, the median offset from 0 degrees is improved by roughly a factor of 3 and the rms about that median is reduced by a factor of ~15. The reduction in phase closure errors holds for both dual and full polarization data sets. The Band 9 data set (without LO offsetting) does not show obvious phase closure errors but the signal to noise is not sufficient to make a precise estimate of phase closure problems.

Observations

Data were taken on three days, as summarized in Table 1.

The Band 3 data were taken with the following calls to DelayCal.py
- DelayCal.py -s 1924-292 -b 3 -P 4 -O -N 4 -r 3 (replace 1924-292 as needed)
- DelayCal.py -s 1924-292 -b 3 -P 4 -N 4 -r 3

Date	Band	Polarization	UID	LO Offsetting	# Antennas
28/Sep/2012	6	Dual	uid___A002_X4ebcca_Xcfb	Yes	8
28/Sep/2012	6	Dual	uid___A002_X4ebcca_Xcda	No	8
29/Sep/2012	7	Dual	uid___A002_X4f01a8_X1fe	Yes	22
29/Sep/2012	7	Dual	uid___A002_X4f01a8_X164	No	23
05/Oct/2012	3	Full	uid___A002_X4fad20_X1126	Yes	13
05/Oct/2012	3	Full	uid___A002_X4fad20_X115e	No	13
01/Oct/2012	9	Dual	uid___A002_X4f1dc9_Xac6	No	14

Table 1 – Summary of observations used to test phase closure with and without LO offsetting

The Band 3 and Band 6 data sets are of high quality and all antennas are included in this analysis. The Band 7 data sets are of low quality, with several antennas having to be flagged. Even after flagging, the Band 7 data are problematic and are not considered in this report. The Band 9 data set is of fairly high quality, though six of the twenty antennas were flagged due to low coherence. The Bands 3, 6, and 7 data sets are TDM with four spectral windows, 128 channels per SPW for dual polarization data and 64 channels per SPW in full polarization data. The Band 9 data set is FDM with 3840 channels native resolution, averaged down to 120 channels to improve signal to noise. Two of the SPWs in the Band 9 data set have 1.875 GHz bandwidth and two have 937.5 MHz bandwidth.

Data reduction and flagging

Though not strictly necessary, data were put through a basic calibration to make assessment of the data quality easier. The steps of the calibration were

1) Flagging
    a. Autocorrelations
    b. Tsys measurements (if present)
    c. Edge channels (observations are TDM)
    d. Problematic antennas or scans (Band 7 only)
2) WVR calibration
3) Split to select the 'science' SPWs / scans and remove cross polarizations (Band 3 only). Split was run again at the end of the calibration to put the calibrated (corrected) data into the data column.
4) Clear the pointing table
5) Bandpass, gaincal, and applycal

The most problematic antennas in the Band 7 data sets were: DV02, DV03, DV07, DV13, and DV20. Some scans also had to be flagged in the Band 7 data sets. Overall, if analysis of Band 7 data is important for testing phase closure, it would be best to get new data with and without LO offsetting. The antennas flagged in the Band 9 reduction and analysis were: DA48, DV03, DV05, DV10, DV21, and PM02. No flagging of antennas or scans had to be done for the Band 3 and Band 6 data sets. Because the calibration done here is antenna based, phase should not have been affected by applying the calibration tables.

The calibration scripts can be found on:
scops02:/mnt/scops/data/data/sschnee/LO_OFF/data/calibrate*.py

Data analysis

Phase closure was calculated on each independent triplet of antennas, for each scan, and for each SPW and polarization. For a triplet of antennas (1,2,3), a phase is measured for each baseline (b), time (t), channel (c), SPW (s), and polarization (p). For baselines $b_{1,2}$, $b_{2,3}$, and $b_{1,3}$, the phase closure is then $b_{1,2}$ (t,c,s,p) + $b_{2,3}$ (t,c,s,p) – $b_{1,3}$ (t,c,s,p), which ought to be equal to zero in the absence of noise and instrumental effects.

The steps to calculate the closure phase are

1) Open the calibrated measurement set and read in the phases for one triplet of baselines, for one SPW, for one polarization
2) Calculate the closure phase for each scan, SPW, polarization, and channel independently

3) Average over time to increase the signal to noise, resulting in a phase closure spectrum (phase closure vs channel) for each SPW and polarization
4) Return the mean and standard deviation of this spectrum
5) Iterate over all triplets of baselines, polarizations, and SPWs

The phase closure scripts can be found on:
scops02:/mnt/scops/data/data/sschnee/LO_OFF/data/band*_phase_closure.py
These scripts call the script:
scops02:/mnt/scops/data/data/sschnee/LO_OFF/data/sls_phaseclosure.py
The steps to estimate the extent of amplitude closure errors

1) Open the calibrated measurement set and read in the phases and amplitudes for one baseline, one SPW, and one polarization
2) Time average the data, leaving phases and amplitudes as functions of channel
3) Determine the percent difference between the observed amplitudes from unity and the variation from 0 degrees phase
4) Determine the magnitude and direction of the total (amplitude and phase) error vector
5) Iterate over all baselines, SPWs, and polarizations

The error vector script can be found in:
scops02:/mnt/scops/data/data/sschnee/LO_OFF/data/band6_mean_vector_amp_error.py
which calls
scops02:/mnt/scops/data/data/sschnee/LO_OFF/data/sls_plotvector.py

All of these scripts can be run in the casapy environment.

Results

In this section we consider only the Band 6 (dual polarization) and Band 3 (full polarization) phase closure, comparing tracks that did implement LO offsetting with tracks that did not implement LO offsetting. The signal to noise in the Band 9 data set was not much lower than the Band 3 and 6 data sets, with noise-related phase closure errors of ~10 degrees expected and measured.

The primary result of this study is that LO offsetting improves both the median and standard deviation of the phase closure spectra. In the Band 3 data sets, LO offsetting reduces the median of the phase closure spectra from 0.45 degrees to 0.03 degrees and reduces the standard deviation of the phase closure spectra from 0.48 degrees to 0.15 degrees. A similar reduction in phase closure errors is seen in the Band 6 data sets. See Figures 1 and 2 for plots showing this result, and Table 2 for the data.

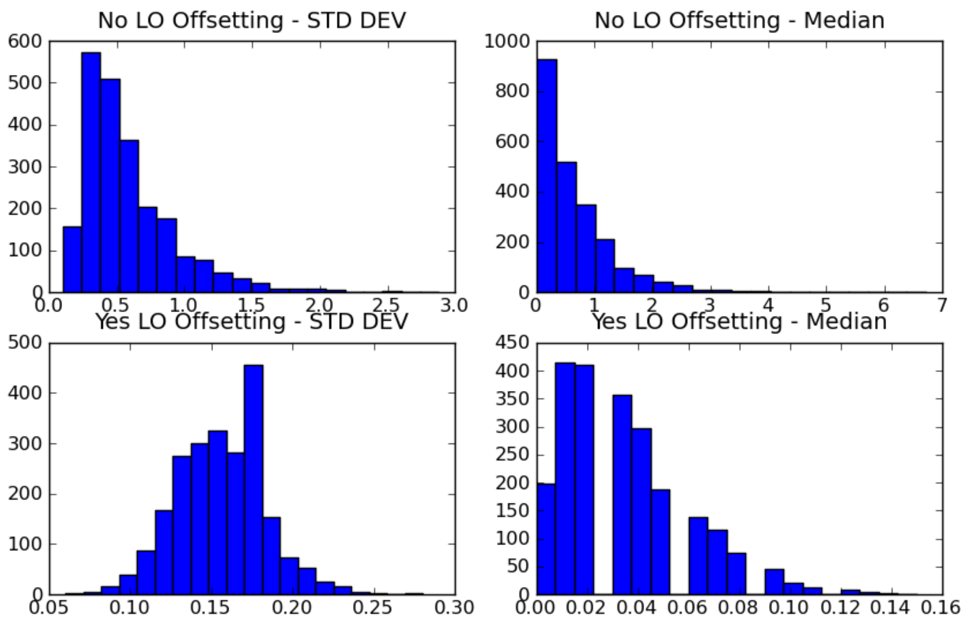

Figure 1 – Band 3 phase closure errors (standard deviations on the left, absolute value of median offset on the right) for data sets without LO offsetting (top) and with LO offsetting (bottom). XX and YY polarizations and all four SPWs are shown. Note that the x-axes are more compressed for the plots with LO offsetting than without. The x-axis is in units of degrees.

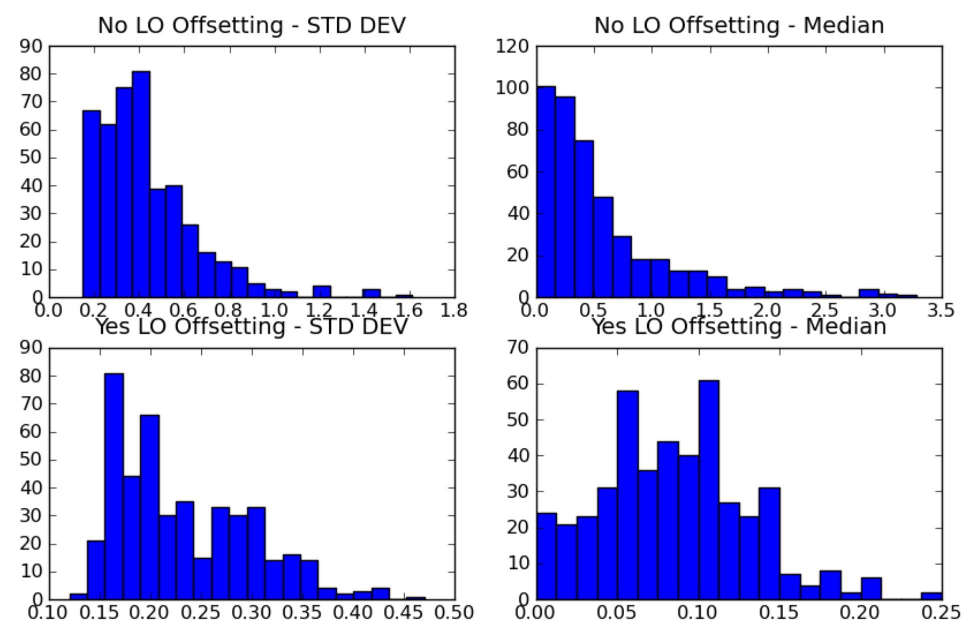

Figure 2 – Same as Figure 1, for Band 6.

A secondary conclusion is that the phase closure errors are not exactly the same for the two polarizations, at least for the case of no LO offsetting. With LO offsetting, the two polarizations become more similar. In the case of the Band 3 data set, the XX polarization has a larger median offset (see Figure 3) and a larger standard deviation (not shown). For the Band 6 data set, the YY polarization has a larger median offset (see Figure 4) and a larger standard deviation (not shown). See Table 2 for the values of the phase closure errors by band and by polarization.

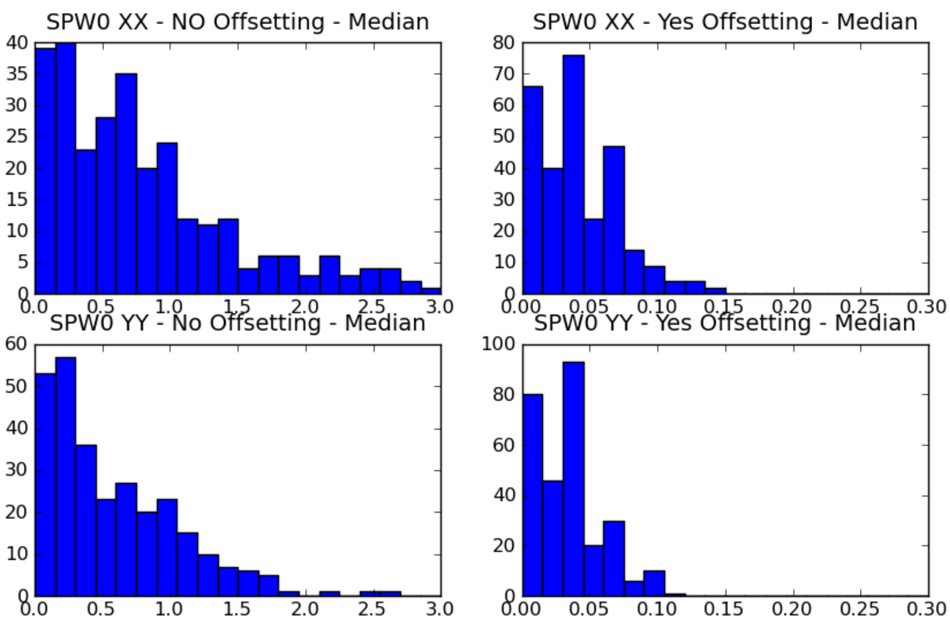

Figure 3 – Band 3 median phase closure offset from 0 degrees for the XX (top) and YY (bottom) polarizations. Data without LO offsetting are on the left, and with LO offsetting on the right. Note that XX polarization has more spectra with relatively poor phase closure than the YY polarization, especially for data without LO offsetting.

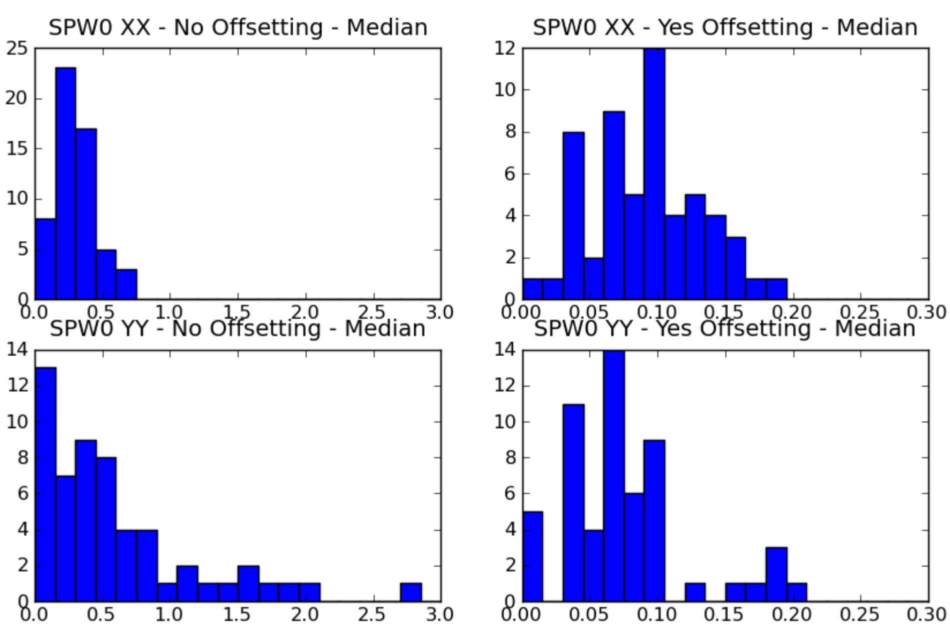

Figure 4 – Same as Figure 3, but for Band 6 data. Note that the YY polarization here shows larger phase closure errors than the XX polarization, for the data without LO offsetting.

There does not seem to be a significant difference between the spectral windows regardless of the use of LO offsetting. This was true in both the Band 3 and Band 6 data sets.

Band	LO Offsetting?	Polarization	Median Error	Standard Dev
3	N	XX	0.51	0.51
3	N	YY	0.42	0.46
3	Y	XX	0.03	0.16
3	Y	YY	0.03	0.14
6	N	XX	0.30	0.35
6	N	YY	0.55	0.42
6	Y	XX	0.09	0.20
6	Y	YY	0.07	0.23

Table 2 – Summary of phase closure errors for the Band 3 and Band 6 datasets, separated by polarization and by LO offsetting

The scripts used to make these plots can be found in:
scops02:/mnt/scops/data/data/sschnee/LO_OFF/data/pc_band*_histogram.py

The plots shown in this report, as well as those plots described but not shown, can be found in:
scops02:/mnt/scops/data/data/sschnee/LO_OFF/data/band*.png

There will always be some phase closure error based on the non-infinite signal to noise of observations. To calculate the expected level of phase closure error, I use the ALMA sensitivity calculator to determine the expected rms of observations based a PWV of 1.262mm (approximately equal to that the Band 6 observations). I find that the sensitivity in one polarization on one baseline is 4.2 mJy for 1.7 GHz bandwidth and 31 mJy for 31.2 MHz bandwidth in 5 minutes on source (approximately equal to the on-source time in the Band 6 observations). Assuming that the flux of 3C279 is 16 Jy, the phase error per baseline is just the noise/signal ratio converted from radians to degrees. The phase closure error is larger than the baseline phase error by a factor of sqrt(3) because it involves the phase measurement on three baselines. The expected phase closure error is 0.03 degrees for 1.7 GHz bandwidth (compared with the 0.08 degrees seen in the Band 6 data with LO offsetting). The expected phase closure error is 0.2 degrees for 31.2 MHz bandwidth (compared with the 0.22 degrees seen in the Band 6 data with LO offsetting). Therefore, the observed phase closure errors are roughly those expected by signal-to-noise limited observations.

The amplitude and phase dispersions around 1 Jy and 0 degrees, respectively, are shown in Figures 5 (no LO offsetting) and 6 (with LO offsetting). As these figures illustrate, the amplitude errors and magnitude of the total (amplitude plus phase) error vector are significantly decreased with LO offsetting. The typical magnitude of the total error vector is 0.23% +/- 0.9% with LO offsetting implemented, and 0.51% +/- 0.24% without LO offsetting.

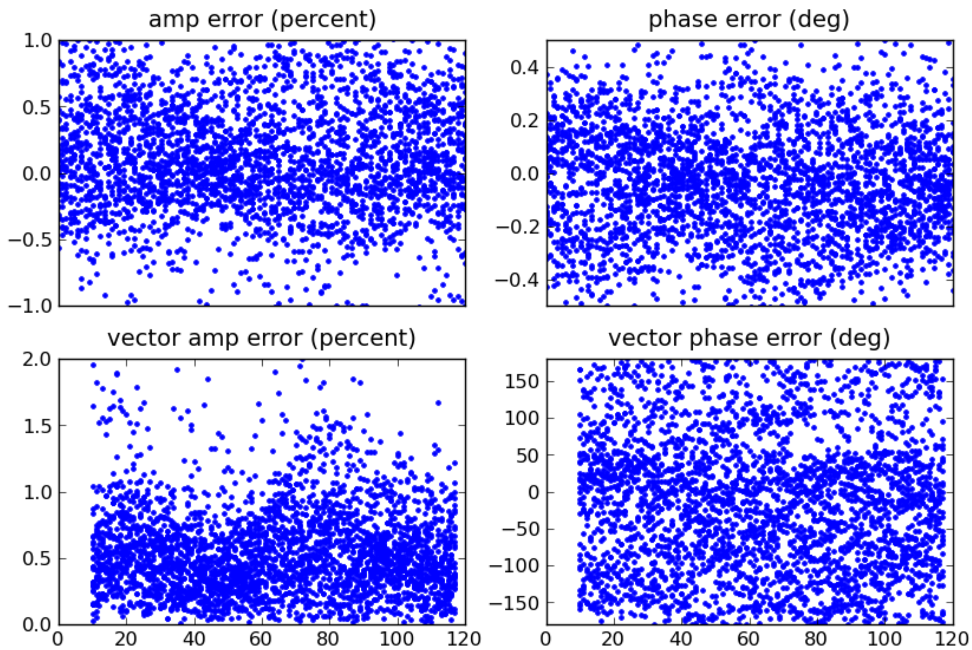

Figure 5 – Variation of the amplitude and phase from 1 and 0, respectively. Data here are from SPW0 and XX polarization from the Band 6 data set without LO offsetting. The x-axis in all panels is channel number. The *top left* panel shows the percent amplitude deviation from 1 Jy. The *top right* panel shows the phase variations from 0 degrees. The *bottom left* panel shows the length of the error vector (combined amplitude and phase). The *bottom right* panel shows the direction of the error vector.

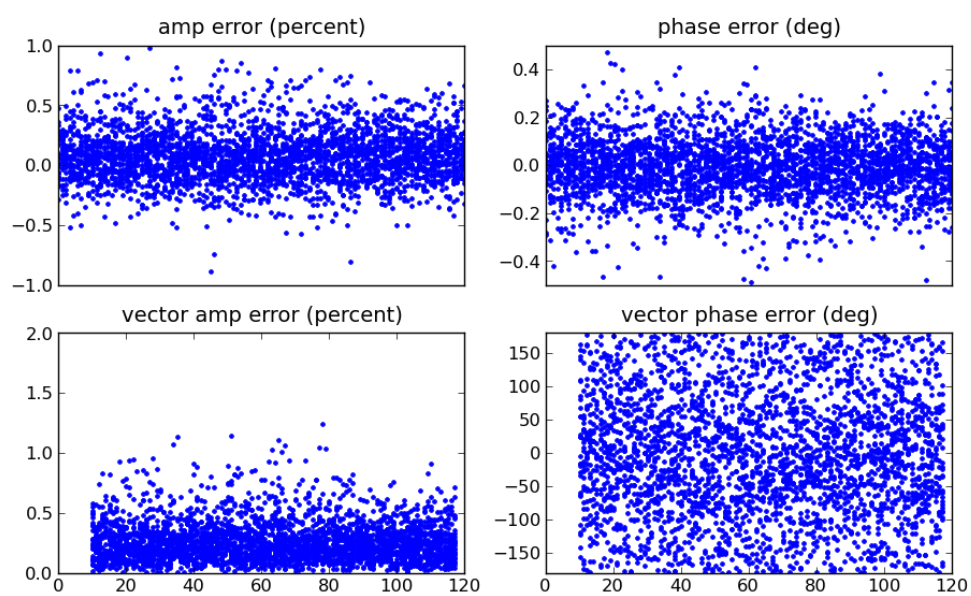

Figure 6 – Same as Figure 5, but for the data set with LO offsetting.

Conclusions

Implementing LO offsetting appears to reduce phase closure errors, both in terms of the offset from 0 degrees and the rms about that offset. The phase closure errors for the observations with LO offsetting are roughly the same for the Band 3 (full polarization) and Band 6 (dual polarization) data sets. For the data sets with LO offsetting, the phase closure errors appear to be consistent with signal-to-noise limited observations. The deviations in amplitude from unity are also reduced by LO offsetting, by just over a factor of two.