LWA Swarm Interferometry

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Observing Strategy

It is of paramount importance to select a strong (>70 Jy) calibrator to use for tracking delays and rates over the course of the observing run (see Table 3). This calibrator should be observed for ∼6 minutes every ∼20 minutes. This strong calibrator should also be useful for bandpass calibration. Preferably, this calibrator should be within 20 degrees of the target, but in any event closer is better. If the target is bright (> 20 Jy) then self-calibration should work to remove any residual phase errors. If the target is faint then phase-referencing will likely be required, although in-beam phase calibration may also be effective for many fields. Demonstrating successful phase-referencing on weak targets is still a work in progress.

Observing can take place day or night. Nighttimes may be preferable for lower levels of RFI and solar interference. Observations should be a minimum of 5 hours duration in order to obtain the best possible (u,v)-coverage. Elevations below 20 degrees should be avoided. Try to observe your target through transit when it is highest in the sky.

We typically observe with an integration time of 1 second. This high time resolution is good for rejecting bursts of RFI. Time average smearing is not an issue for integration times less than 15 seconds. Bandwidth smearing is a much more significant issue. We typically observe using 1024 channels across a 20 MHz bandwidth tuning. This is also good for rejecting narrow band RFI. Bandwidth smearing using the 512 channels (0.04 MHz resolution) allows imaging of the full primary beam but requires a lot of compute, even for a small number of baselines.

The observing files themselves should be constructed using the LWA Software Library SwarmGUI tool from the session_schedules repository.

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1 Introduction

This guide is to help in the calibration of interferometry data taken using the LWA Swarm Interferometer. Calibration is done using the Astronomical Imaging Processing Software (AIPS) and we assume that the user has been introduced to the basics of AIPS martial arts.

We are still in the process of finalizing this guide in association with a forthcoming publication, so these steps could be subject to change (but not likely). Likewise, if there are difficulties using the guide, alert one of the authors.

Brief startup on Virgo:

\>>> source ∼gtaylor/aips/LOGIN.SH
\>>> aips tv=local:3

Craig's Note: Always check your inputs page before running the code, and pay special attention to version numbers and file names. Use getn and uc to more safely input and output the files into functions, makes it harder to get the ext/name wrong. Continuously use POSSM and imh to check your work. Don't give up! Ask questions! You got this!

2 Calibration Steps

The following are instructions for basic calibration of LWA Swarm Interferometry -observations. Individual steps are named after the primary AIPS task used for that particular set of reduction and each will have to be manually configured according to the brief here. For each task we identify important input parameters that need to be adjusted to appropriately apply the calibration for LWA observations. Users are encouraged to explicitly pay close attention to the adverbs before running commands to avoid making mistakes and to check their work after each step using LISTR and POSSM.

For the following steps we define that the main calibration target used be called 'YourCal', meaning in practice at these locations you would input the name as it appears in AIPS in this field. *For example, If I have observed the calibrator source 3C380 during an observation, I would replace 'YourCal' with '3C380'.* In this guide, we also at times use the equal sign (=) to indicate values which variables are set to, but they are not strictly required in most cases when in the termina.

1. FITLD: set DATAIN with new files extension session '.FITS_'. Be sure to set CLINT=10/60 to get 10 second entries in the CL table, remember to set the ncount=*value*.

2. If there is a BP table created by FITLD you will want to delete that using extdest.

3. Use LWA1 for the reference antenna. This is refant = 51 (or after October 2024 refant = 1).

4. LISTR: Use optype 'SCAN' to show the observed times.

   LISTR is also used with the optype 'GAIN' to view coefficients saved into the SN and CL tables. This can be done by using optype 'GAIN', inext='CL' or 'SN', invers=*table_version*, and changing dparm(1) to the desired value according to the description in the inp menu.

5. FRING: calsour='YourCal', docal = -1, snver = 0, dparm = 1 8000 800 1, aparm(6)=2, timer= choose 2 min from a scan, rest are pretty much defaults (zeros or blank). Remember here to pick a scan in the middle of the observation with our fringe-fitting calibrator source, somewhere that the rates look low and the SNR is high as the task runs.

   After running, then use 'save clocks'.You can get a head start on inputs by invoking 'get clocks' (but only if you previously had the foresight to 'save clocks' after this step). If you don't get solutions for all antennas then try another scan or calibrator. You might also try a larger delay window. If the delay is beyond 10,000 nsec then consider asking for recorrelation.

6. SNCOR: timer = 0, snver = 1, opcode 'mula', sncorprm = 10 0, antennas 0, bif,eif = 0. *Do not apply this 10x multiplier to VLA antennas in eLWA runs*

7. CLCAL: sources=' ', calsour=' ', timer 0, opcode='calp', gainver=1; gainuse=2, 2pt interpolation, snver 2, invers 2.

8. FRING: timer 0, bparm (use a smaller window like) 1 2000 200 1, snver 3, docalib 1, gainuse 2, aparm(6)=2, calsour = '' or run on each calibrator source making sure output all goes into the same SN table. This step imposes our Fringe solutions from clcal table 2 back onto 3C380, should eliminate the bulk offsets in the data. The remaining residuals will be from inaccurate geometry and ionospheric effects.

9. CLCAL: sources='', calsour='YourCal', snver 3, gainuse 3, gainver 2. Table 2 here should have all of those bulk offsets to apply onto the rest of our calibrators and targets. If you aren't transferring solutions to targets then use interp 'self', otherwise use interp '2pt'.

10. At this point it is a good idea to do a LISTR of your CL table 3 to make sure that all calibrators and targets have meaningful amplitudes (10) and delays for all antennas and times.

    Next we are going to do some quick and dirty rfi flagging. Using POSSM and making a cross power spectrum on a short sequence of data we inspect the band using bchan/echan. If there is RFI we can excise it using UVFLG, remember to double check after in possm too.

11. POSSM: aparm 0, docal=1, gainuse=3, timer=choose 2 minutes. If there are any RFI spikes in the band you can use UVFLG to select which IF, Baseline, and Frequency channels to mask. This will write to a FG table that you will make sure to use for future tasks that ask for an FG table.

12. BPASS: flagver 1, calsour='YourCal', timer 0, soltyp='L1R', gainuse 3, docalib 1, bpassprm(10) 3, solint -1, doscale=-1. This will perform the bandpass calibration on your observation.

13. POSSM: aparm(8)=2 to plot the bandpass. plver # to choose PL table, go tvpl to view. Make sure bandpass for all antennas looks smooth. Should roll off gently at both ends. If you see spikes then use UVFLG to get rid of bad ant/chan/pol combinations and make a new BP table with the updated flagging.

14. SPLAT: source ”; bchan=81, echan=961, gainuse=3, docalib=1, aparm(1)=3, outnam=innam, outcl 'splat', outseq=0, doband 1, channel=22, chinc=22, solint 0. This is going to average our 1024 frequency channels into 40.

    After this splat is where we will put in the coefficients that we have solved for to normalize amplitudes to a reference level of 100Jy. To do this we used the following steps:

15. CALIB: calsour='YourCal', docalib -1, solint 0.5, doband=-1, solmode='P', snver 1, cparm 0, aparm(9) 1, timer = 2 minutes only (we will keep this bad soln, don't panic, but do make sure that there are entries in the SN table for all antennas and polarizations).

16. SNCOR: timer = 0, antenna=# 0, sncorprm=*value* 0, opcode 'mula', IF=# where you have to run through antennas 1, 2 and 3, and IFs 1 and 2 so you will make 6 new SN tables. The values come from the table. Make sure you increment SNVER every time you run it. Be sure to run LISTR with aparm 0 to make sure that your final SN table has the right values for every antenna and IF.

17. CLCAL: source ”, calsour ”, gainuse 2, gainver 1, snver 7, inter '2pt', inclass is SPLAT here still.

18. LISTR to make sure that the desired values got placed in the CL table for each source/antenna/IF, optype 'gain'.

    NOTE: As an alternative to steps 15-17 you can use SWCAL(N) where N is the catalog number of the SPLAT file used in step 14. To use it you first have to set vers='runfil', then type ”RUN SWCAL” then SWCAL(N).

19. SPLAT: docalib=1, doband=-1, bchan=1, echan=0 , aparm=0, chinc=1, channel 1; outcl=SPLAT, oseq=0, gainuse 2; solint 0.

20. MORIF: bif=1, eif=0, npiece=20, outcl=MORIF. Here we will split the observation into more intermediate frequencies instead of many channels which is helpful when imaging the data.

21. SPLIT: sources 'SrcName', aparm 2 0, nchan=0, chinc=0, bchan=0, echan=0, gainuse 1, outcl=SPLIT. This task is used to separate single sources from

multi-source uv data, so you will change ‘SrcName’ and write a .SPLIT file for each source.

22. FITTP: save the split files out to the desktop, change dataout to where you want to save it. You did it!

LWA-NM Interferometry Ampl. Coeffs after 8/6/24

Antenna	Tuning1	Tuning2
51 (LWA1)	20	33
52 (LWA-SV)	55	67
53 (LWA-NA)	111	110
54 (OVRO-LWA)	55*	67*

Table 1: Running log of the amplitude coeffs for LWA-NM Inteferometry. This is from after the August 6th changes to fix the high frequency sensitivity. Based on 110 Jy for 3C298 at 50 MHz. (*provisional values for OVRO-LWA)

LWA Swarm Calibrator Targets (A423)

Source ID	RA (J2000)	DEC (J2000)	Obs. Date	S_ν (Jy)	MajAx (as)
4C 58.02	00 36 08.02	+58 55 49.6	12/22/2024	42	28
3C 20	00 43 08.71	+52 03 29.1	12/22/2024	37	34
3C 27	00 55 59.69	+68 22 23.6			44
Cul 0106+13A	01 08 50.82	+13 18 38.2			46
3C 41	01 26 44.4	+33 13 11	09/26/2024	42	24
3C 47	01 36 24.35	+20 57 21.0			76
3C 48	01 37 41.41	+33 09 38.2	09/26/2024	119	24
3C 69	02 38 02.27	+59 11 55.0			51
3C 84	03 19 47.72	+41 30 40.7			69
3C 123	04 37 04.46	+29 40 15.3	09/25/2024	71	32
3C 134	05 04 43.17	+38 06 30.4			93 /24
3C 147	05 42 36.04	+49 51 07.9	09/25/2024	68	27
3C 154.0	06 13 49.81	+26 04 38.6			51
3C 161	06 27 10.1	-05 53 06	10/04/2024	80	40
3C 196	08 13 36.22	+48 13 02.5	10/04/2024	113	30
3C 208	08 53 08.57	+13 52 54.3			27
3C 216	09 09 33.50	+42 53 48.3	10/12/2024	58	26
3C 234	10 01 48.69	+28 47 07.3			94
3C 244.1	10 33 33.76	+58 14 33.6			47
3C 254	11 14 38.02	+40 37 17.6			32
3C 268.1	12 00 22.55	+73 00 48.6	01/09/2025	49	36
3C 280	12 56 57.16	+47 20 21.7	01/09/2025	46	30
3C 286	13 31 08.28	+30 30 32.96	09/03/2024	44	33
3C 295	14 11 20.24	+52 12 06.6	09/03/2024	142	28
3C 298	14 19 08.18	+06 28 34.80	09/03/2024	117	31
3C 309.1	14 59 08.39	+71 40 20.6			29
3C 330	16 09 36.56	+65 56 43.3			62
3C 338	16 28 38.11	+39 33 01.8	12/26/2024	n/a	87
3C 348	16 51 07.98	+04 59 35.54			62
3C 368.0	18 05 06.60	+11 01 31.3	12/26/2024	48	32
3C 380	18 29 31.78	+48 44 46.16	12/26/2024	84	27
3C 388	18 44 02.38	+45 33 29.62			31
3C 394	18 59 23.64	+12 59 08.4			28
3C 409	20 14 27.62	+23 34 55.8	11/03/2024	117	31
3C 410	20 20 06.37	+29 42 20.9			37
3C 427.1	21 04 07.89	+76 33 09.7	11/03/2024	57	27
3C 430	21 18 18.68	+60 48 14.0			72
3CR 431	21 18 52.40	+49 37 03.3			45
3C 433	21 23 44.63	+25 04 14.9			34
3C 438	21 55 52.23	+38 00 27.9	11/03/2024	61	29
3C 468.1	23 50 55.52	+64 40 09.6			24

Table 2: Collection of Swarm Results per Source (all values use map-scale=arcsec, mapsize=512,1). The selection criteria for sources used the VLSSr catalog and the VLA calibrator list to compile sources. The foundation for the sources came by filtering the VLSSr for targets with a Declination $> 10°$ and a 74MHz flux density of > 40 Jy. This was supplemented by sources with from the VLA Calibrator list used in the commissioning of the LWA-NA station in with LWA Swarm observations.