LBWG memo 30

Nenufar tests

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Observations

Observations of 3C147 were taken with the LOFAR array incorporating Nenufar on 26 August 2021. The observations were an 8-hour track on target, with the LOFAR LBA including all international stations except DE601 and DE604. Observations were pre-averaged to 1 sec, 64 ch/subband (3.05kHz). A second observation with FR606 instead of Nenufar was taken but has not yet been processed.

Processing of the data.

Ten subbands around 51 MHz (SB100-109) were selected and averaged by a factor 4 in frequency to 16 ch/subband, before the following steps:

- Beam correction (`applybeam` in NDPPP)
- Combination into a single file, output to FITS format and reading into AIPS
- Conversion from linear to circular polarization using a Parseltongue script (`lin2circ.py` and `mscorpol.py` were both found to run extremely slowly on the measurement set)
- Multiplication of weights by 10^6 (thereby avoiding underflow problems previously observed in AIPS with very small weights)
- Derivation of delay solutions using `FRING`, assuming that dispersive delay can be approximated as linear across 10SB (approx 2 MHz). Simple application of `FRING` produced the same bad solutions as are often seen with the pipeline, where the solution jumps between two delay values, both of them wrong. The cause is delays which are outside the effective delay window. A delay window of 4μs was needed, together with a uv-cut at 40 kλ, an L1R solution with a S:N cutoff of 2, and a solution interval of 1 minute. Phase solutions were derived through this process and then zeroed.
- Delay solutions were edited by hand and inspected (Fig. 1), then interpolated.
- Phase solutions were derived using a 30-second solution interval, applying the delay solution, inspected and interpolated (Fig. 1). Both phase and delay solutions look similar between R and L polarizations.
- The processed data on baselines between CS001 and international stations was written out for inspection of signal to noise.
- Bandpass and amplitude calibration solutions were attempted. Bandpass solutions did not work well. Amplitude calibration was done with a 1 hour solution interval.
- `IMAGR` was used to produce the image of Fig. 2, with a 40 kλ uv cut. Fitting to the image suggests that the image is not a point, with a deconvolved size of 610$\times$240 mas in PA 52, which is approximately the orientation seen in other, GHz-frequency images.

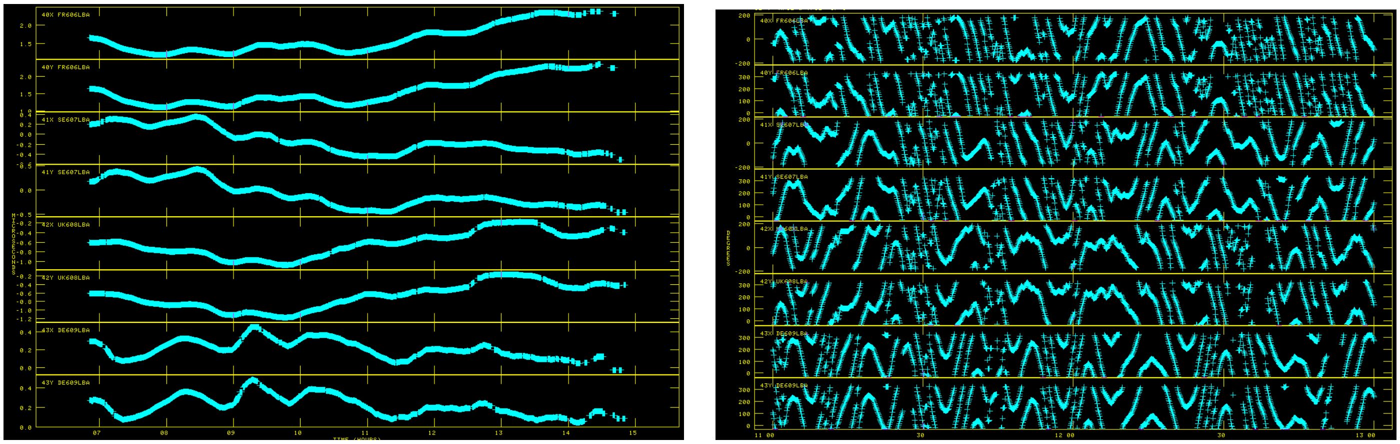

Figure 1: Delay and phase solutions on four antennas (FR606, SE607, UK608, DE609). Delays vary but can reach $> 2\mu$s. Solutions are independently derived for R and L polarizations (marked X and Y in the plots) and are reassuringly consistent.

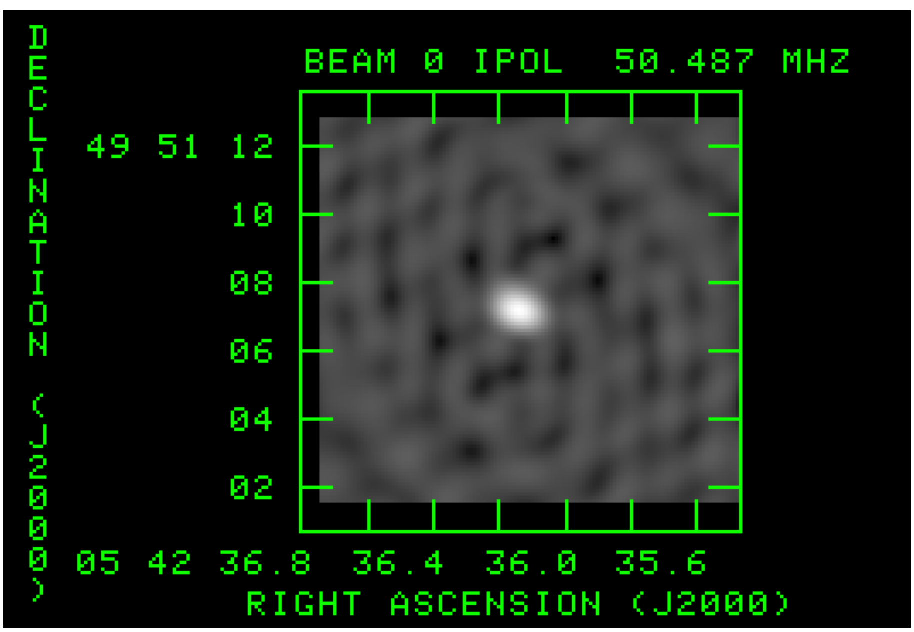

Figure 2: Image of 3C147. The beam is 0.91×0.76 arcsec in position angle $85°$.

Statistics

The array of data has dimensions `[tel=13,time=400,channels=160,pol=4]` and is available online[1]. It consists of baselines from CS001 to 13 telescopes, in the usual LOFAR ordering but without DE601 and DE604; hence FR606/Nenufar is the fourth element. For the R polarization the following was done:

- Baselines to four antennas (DE602, FR606/Nenufar, SE607, UK608) were extracted in the form of a 2-dimensional array in time and frequency. These all have approximately the same length and therefore should resolve the source close to the same extent.
- Each array was blanked in regions of low signal and then flatfielded by dividing out, first the scalar-averaged amplitude response as a function of frequency and then the scalar-average response as a function of time; the array was then normalised so that the mean of the real part was 1. The phase calibration of the data ensures that the mean of the imaginary part is then approximately zero. Fig. 3 shows the data arrays before and after this process.
- The real-vs-imaginary scatter plots were produced for these arrays (Fig. 4). It is clear that FR606, with the same normalized signal, has lower scatter than the other three, which all have very similar scatters.
- With the normalized signal (normalized to 1 in the real part), the relative scatters, expressed as standard deviation of the real part, are 1.288, 0.787, 1.419, 1.422. Taking UK608=1, the relative signal-to-noise is 1.10,1.81,1.00, implying an improvement of a factor $\sim$1.8 in the Nenufar baseline (or 3.3 in collecting area).
- This factor is constant to $\pm$0.1 if different time slices through the data are taken.

Other pipelines

The LoLSS/de Gasperin LiLF pipeline has been partly run; this is explicitly designed for LBA data so should produce a better image. This is likely to rely on a model for 3C147 for running it further.

The standard LOFAR-VLBI pipeline should work on these data, as there is no reason why LBA data are not able to be processed. Currently the prefacet routines, using the recommended LBA flag and other settings, are giving results that need further investigation (Fig. 5-7). The delay on Nenufar is also likely to be a problem for the delay calibration.

Conclusions, opinions and possible problems

- The investigation at 51 MHz shows an advantage of 1.8 in signal-to-noise of Nenufar over other international stations (DE602, UK608, SE607) which is consistent between the three other stations, which have similar baseline lengths to CS001 (DE602 = 577km, FR606 = 699km, SE607 = 600km, UK608 = 599km), although the slightly longer baseline length to FR606 may mean that 1.8 is a small underestimate. (Further investigation is needed using Borowiec, or by comparing with the FR606 LOFAR station).

[1] `https://livemanchesterac-my.sharepoint.com/:u:/g/personal/neal_jackson_manchester_ac_uk/EYm2eWnDibRPvRsQtq45LZwB3tco7NYJSaH-RTxpPaOSXw?e=UqtKSz`

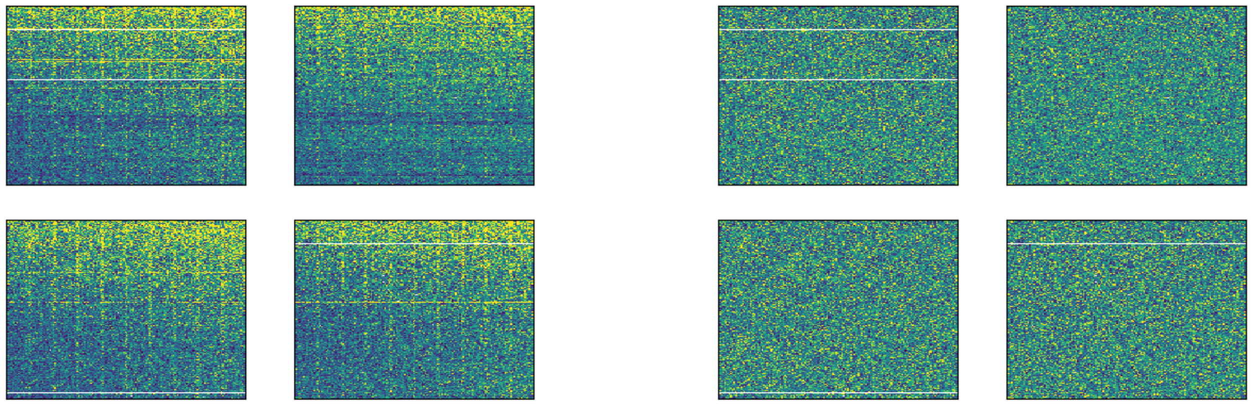

Figure 3: Amplitude vs. phase and frequency, before (left) and after (right) flatfielding. Each panel contains four baseline to CS001: DE602 and FR606/Nenufar (top), SE607 and UK608 (bottom). Each plot is scaled from 0 to twice the mean in the plot, so the lower noise in FR606 is just visible.

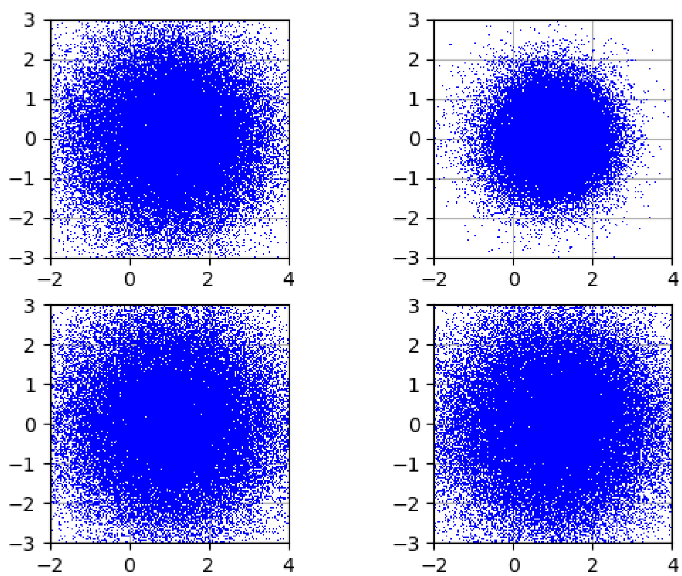

Figure 4: Real vs. imaginary plot of visibilities for four baselines to CS001: DE602 and FR606/Nenufar (top), SE607 and UK608 (bottom). The data has been normalised to have a mean at 1 in the real part.

- Although the data have been corrected to circular polarization, so that Faraday rotation should affect only the left-right phase difference, there is still a significant (10-20% signal, sometimes more) in the cross-hands[2]. In theory this could affect S:N comparisons if more signal is leaked off in one station than another.

- There may be some reduction in correlation due to averaging because of residual errors in phase and/or delay, although this is unlikely (the histogram of the real part of the FR606 amplitudes is quite symmetric with the median being within 1% of the mean).

[2] Also noticed by Francesco de Gasperin in other datasets

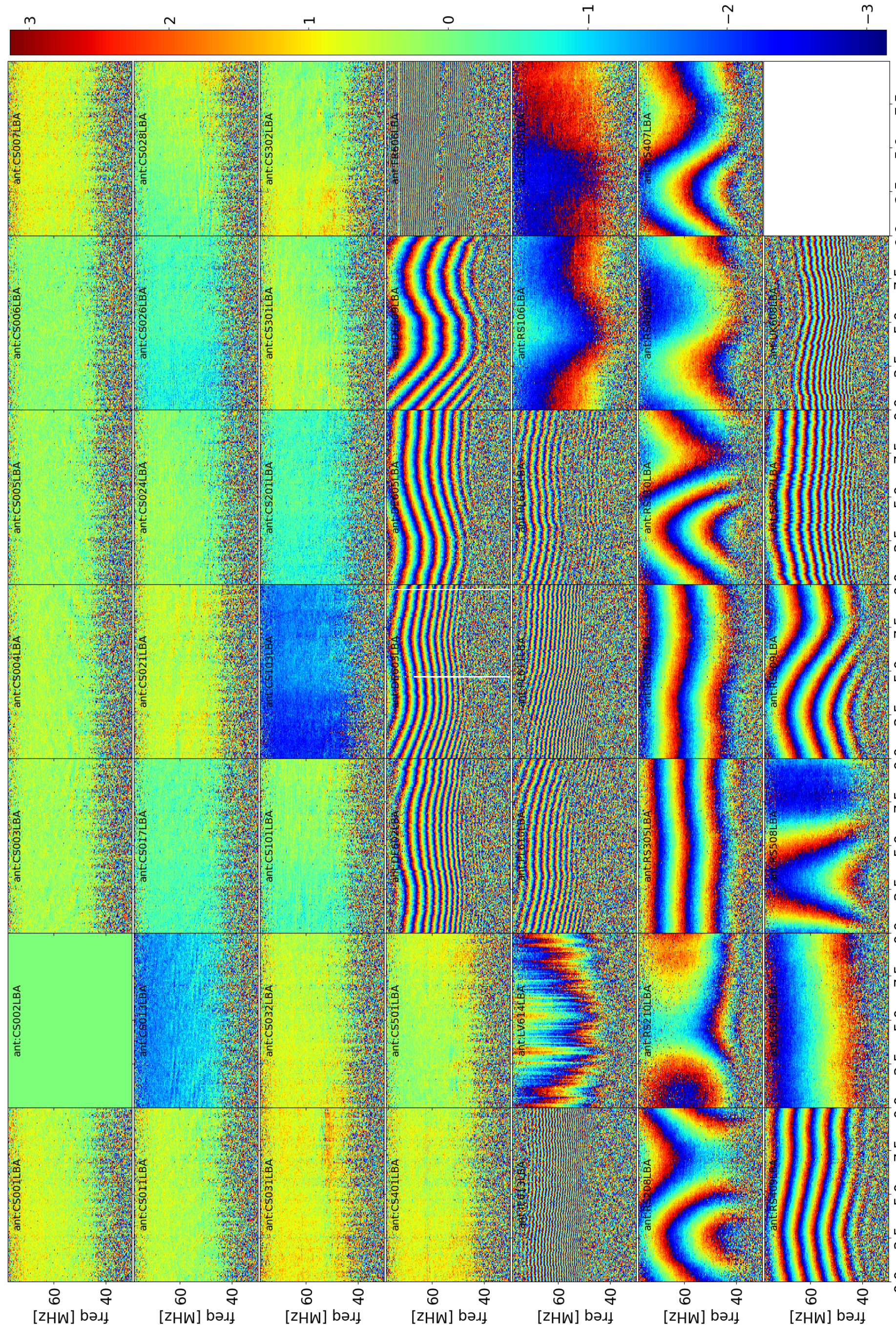

Figure 5: `Pre-Facet-Calibrator polalign_ph_polXX.png`

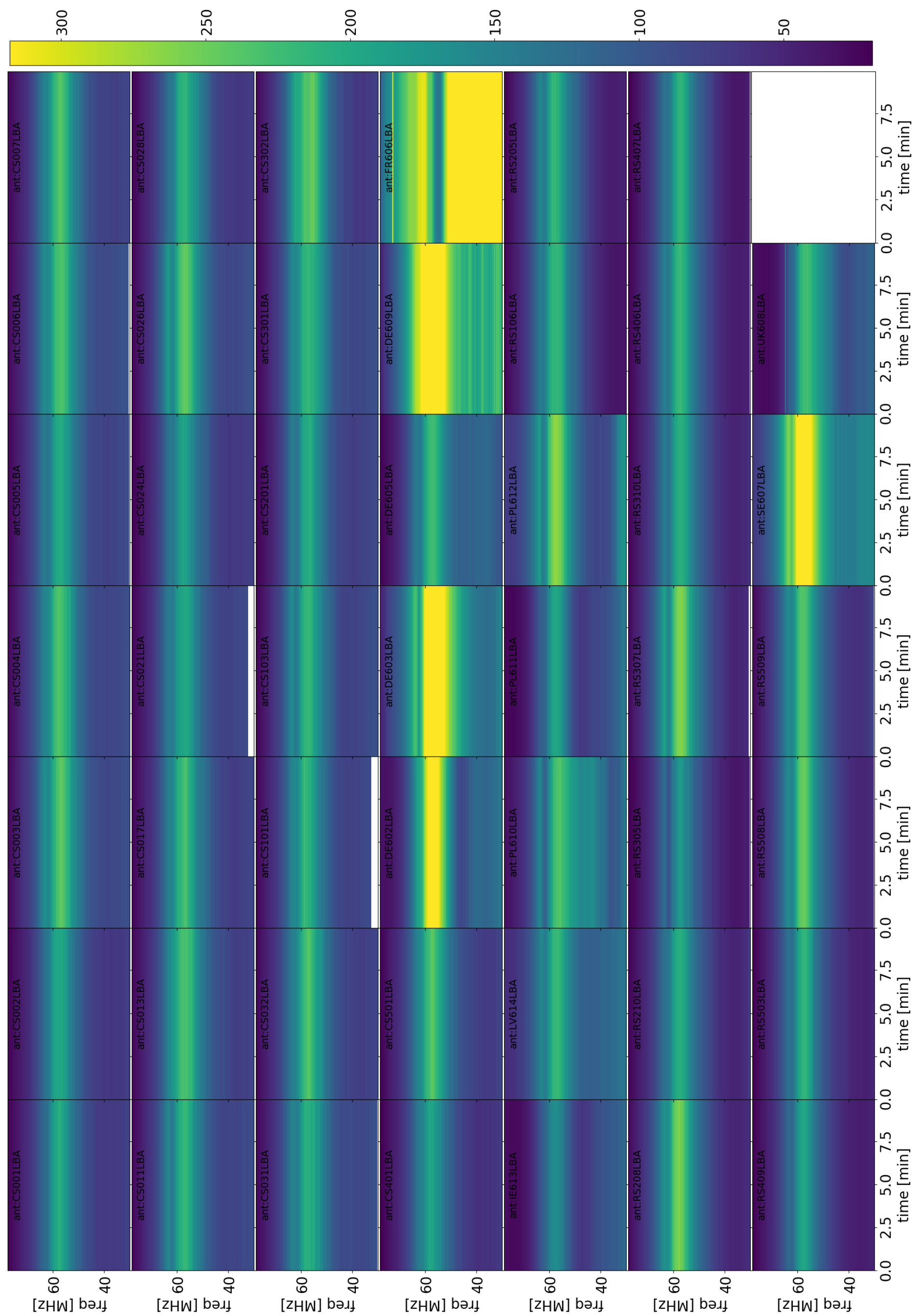

Figure 6: `Pre-Facet-Calibrator polalign_ph_polXX.png`

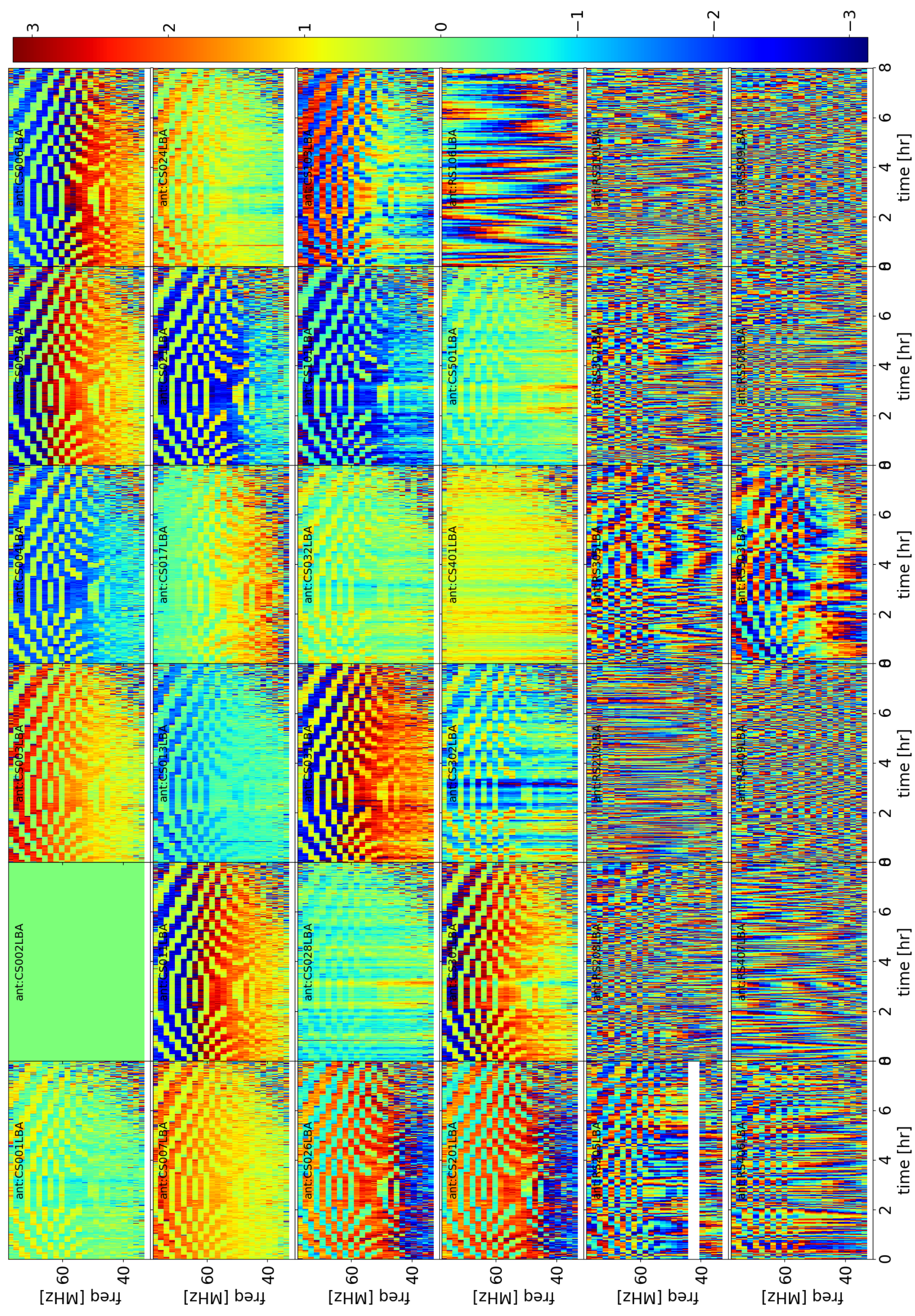

Figure 7: `Pre-Facet-Target ph_polXX.png`