VLA SCIENTIFIC MEMORANDUM NO. 152

Non-Closing Offsets on the VLA

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March 1984

Recent efforts to obtain very high dynamic range in VLA maps of 3C 120 have shown the value of correcting for non-closing offsets in the data. Non-closing offsets are offsets in amplitude and phase that violate the principle, upon which VLA calibration is based, that all calibration is antenna dependent. For dynamic ranges below a few thousand to one (peak to rms) the non-closing offsets will not significantly affect maps, especially of high declination sources. This is because the magnitudes of the offsets are about one percent (the largest are about 3 percent) and the effects in the map plane are reduced by about the square root of the number of baselines, ie. about the number of stations. However the offsets set a limit to the dynamic range obtainable from the data. Also, for declinations where there are systematic patterns of non-crossing tracks in the uv plane, the offsets can cause degradation in specific parts of a map. An example is the degradation seen to the north and south of bright points in maps of sources near the equator.

Non-closing offsets that are constant on time scales of hours or longer can be measured with appropriate calibrator observations and removed from observations of a program source. Significant improvements in maps of 3C 120 (declination about 5 degrees) from two different observations were obtained by such calibration. The method used for the calibration was:

1) A bright point source was observed as a calibrator during the VLA observations.
2) The point source was self-caled with ASCAL in AIPS assuming that it was really a point source of 1.0 Jy. The gains were allowed to float so that the output points were fractional offsets due to non-closing effects. Any closing offsets were removed by the self-calibration. The calibrator needs to have less than a few tenths of a percent of its total flux density in resolved components.
3) The derived offsets were used to correct the 3C 120 data using two AIPS tasks, BCAL1 and BCAL2, specially written for the job. These tasks are available in the 15 Mar. 1984 version of AIPS.

The first of the two observations was made with the A array in in October of 1983. Normal phase calibrators were not observed on the assumption that 3C 120, with the help of self-cal, could be its own calibrator. However, several observations of 3C 84 were made at intervals of about 1 to 2 hours for both instrumental polarization calibration and for calibration of non-closing offsets. Data were taken at 2, 6, and 20 cm. The 20 cm data are not yet reduced. The corrections for non-closing offsets were made to both the 6 and the 2 cm data and for both AC and BD IF's. In all cases, significant improvements in the maps were obtained. An example is shown in Figure 1 which shows the 6 cm, AC maps made from uncorrected and corrected data after the self-cal iteration at which the corrections were applied. A significantly better map was obtained after adding the BD data and doing further self-cal iterations,[1] although the noise level is still about 4 times theoretical.

The second data set consisted of 6 cm, B array observations made with the phased array during a VLBI run in July of 1982. The non-closing offsets were measured using about 1.5 hours of observations of 0552+398 (DA193 - about 5 Jy) which was being used as a VLB calibrator. The 0552 observations were made after 3C 120 had set so they correspond to a slightly different time than the 3C 120 data. Figure 2a shows the results after 5 self-cal iterations and after 2 antennas that seemed to have some of the worst offsets were editted. Figure 2b shows the next iteration, made using clean components from iteration 5 as an input model and

[1] The large number of self-cal iterations, 19, constructively used in this effort is disturbing in its implications for the future computer needs of the VLA and VLBA. The number could be reduced by a few with hindsight, but not by a factor of two without significantly different, and as yet undetermined, methods. It seems to take a lot of iterations to pull up large scale, low level flux in very high dynamic range maps. Other observers, after hearing of these results, have tried large numbers of self-cals, also with positive results. This should be explored further.

using data, with all stations present, that has been corrected for non-closing offsets. The improvement is dramatic. For a box south of the source, including both some of the n-s crud and some of the cleaner parts of the map (corners 156,145 and 356,245 on a 512 by 512 field), the rms improved from 0.36 mJy/beam to 0.11 mJy/beam - over a factor of 3! The improvement was not due to the extra self-cal iteration. The improvement between iterations 4 and 5 was almost impossible to see. Note that the peak to rms in the corrected map is 29,000. Some further improvement was obtained with 2 more self-cal iterations. The rms in the above box in the final map was 0.099 mJy/beam. In another box outside the region of the n-s crud, the rms was 0.063 mJy/beam giving a peak to rms of 50,000. But still the final map has a noise level about 3 times theoretical, so there is still room for improvement.

A test data set with no noise and no instrumental offsets, but with the same uv coverage as the Oct. 1983 data used for the maps in Figure 1, was constructed with UVSUB using the first 150 clean components of an early map similar to those in Figure 1. The object was to test the limitations imposed on the dynamic range by software. The ratio of peak to rms in the CLEAN residual map was 110,000.[2] When the non-closing offset corrections used on the real data were applied to the test data set, introducing offsets equivalent to real ones but of opposite sign, the ratio was reduced to 12,700. This must be about the limit to the quality of the maps that can be obtained with the VLA without corrections. The higher dynamic ranges achieved on 3C 120 after corrections demonstrates the value of the corrections.

The non-closing offsets clearly set the limits on dynamic range currently obtainable on simple, strong sources with the VLA. Therefore, a serious effort to understand and correct them is justified. Further tests need to be done to determine the time scales of variation of the offsets and to determine the source of the offsets. Also the calibration method needs to be generalized to allow the use of partially resolved calibrators (eg. ASCAL needs to catalog its divided data set).

[2] This required correlated roundoff errors in the map and beam since they are stored as 2 byte integers with a maximum resolution of about 64,000. This was possible because 3C 120 is dominated by its core. The ratio was reduced dramatically when the core was moved off a grid cell. With a 0.4 cell shift in both directions and 3 points per beam, the ratio was only 7000!

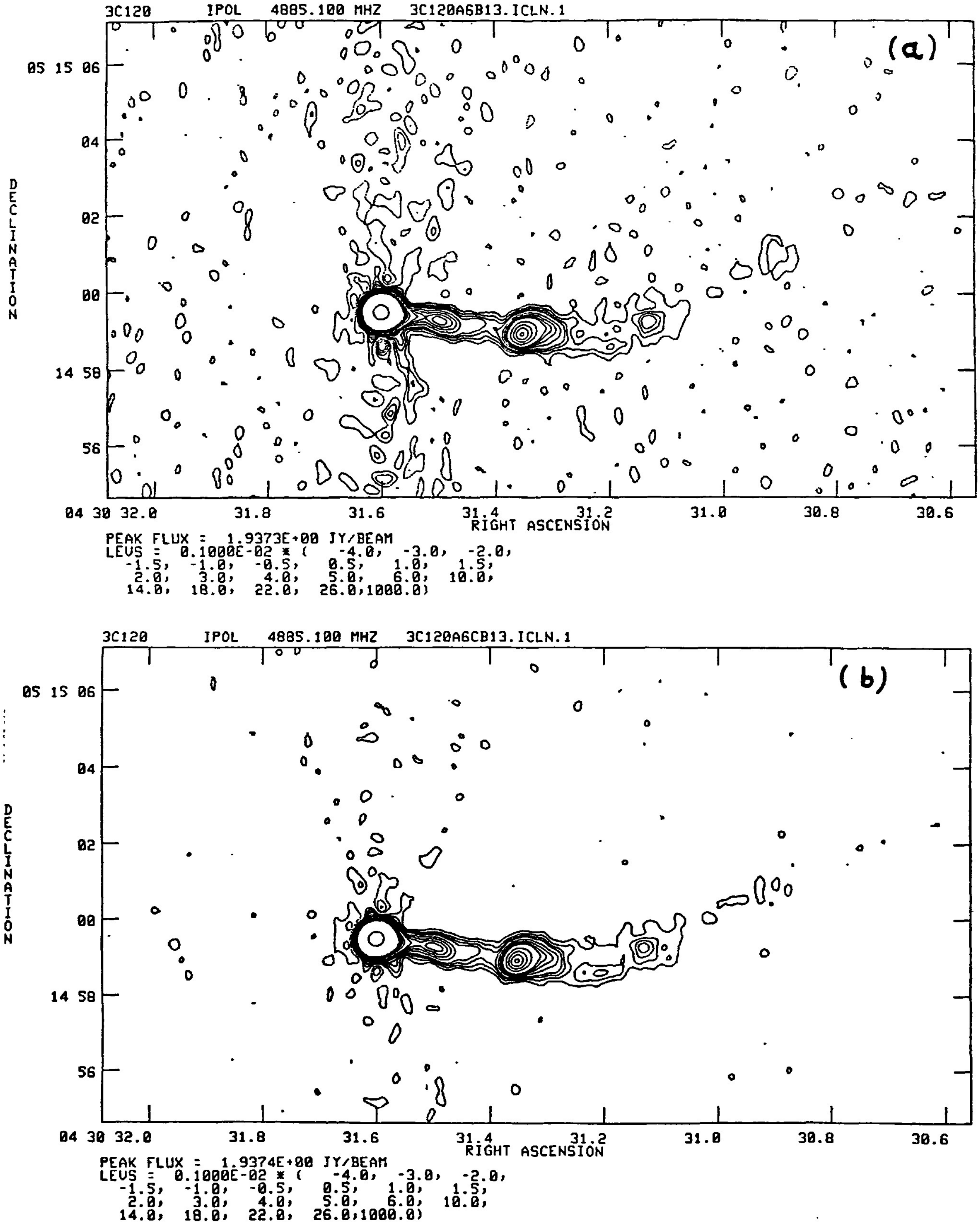

Figure I. Maps of 3C 120 made with data taken on the A configuration of the VLA in Oct. 1983. The top map (a) was made from data that had not been corrected for non-closing offsets. The bottom map (b) differs from the top map only in that corrections, based on observations of 3C 84, have been made for non-closing offsets. The data set contains 47,000 one minute visibility records.

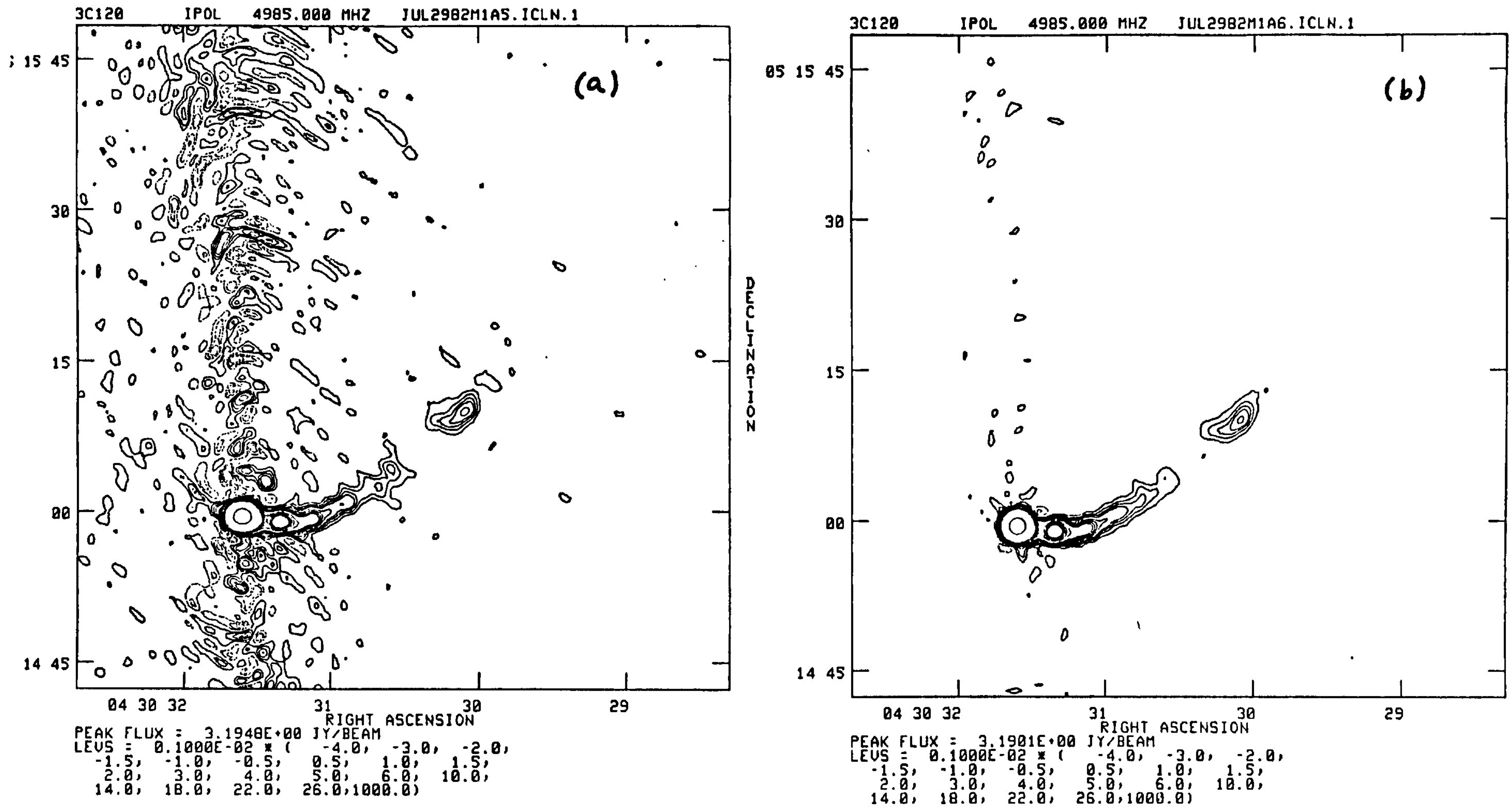

Figure II. Maps of 3C 120 made with the B configuration of the VLA during phased array VLBI observations in July 1982. The left hand map (a) was made before the data was corrected for non-closing offsets. The right hand map (b) was made using data corrected for non-closing offsets derived from observations of 0552+398. The data set contains 118,000 one minute visibility records.