Note on Polarization Calibration of the EVLA

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***Abstract*—Determination of the spurious instrumental polarized response to unpolarized emission in radio interferometers such as the EVLA has traditionally been done using a calibration relative to one feed on one antenna which is assumed to be nominal. Wide-band systems using circularly polarized feeds such as are used on the EVLA have relatively high instrumental polarization and an absolute calibration using the second order terms becomes feasible. In the following, an example case is shown for which the absolute calibration gives dramatically lower polarized imaging artifacts than the relative calibration as practiced in the Obit package. The relative calibration seems not to be performing as intended.**

***Index Terms*—Radio Interferometry, image artifacts, polarization calibration**

I. Introduction

TRADITIONAL calibration of the instrumental polarization of short baseline interferometers such as the EVLA have determined the calibration parameters relative to a reference feed on a reference antenna [1], [2]. The equations describing the instrumental polarization are degenerate to first order unless the calibration source is observed with a significant range of parallactic angles at a given time (e.g. VLBI); the EVLA is designed to always have the same parallactic angle at all antennas. Fixing the parameters of one feed breaks this degeneracy. The possibility of using higher order terms to break this degeneracy is explored in the following. The example shown here uses the Obit package ([3], http://www.cv.nrao.edu/∼bcotton/Obit.html).

II. Instrumental Polarization Calibration

The response of antenna feeds to incoming radiation can be characterized as either the complex factor times one of the orthogonal polarizations that gets added to the other ("leakage" or "D terms") or as the ellipticity and orientation of the ellipse of the radiation which the feed would transmit. The implementation in Obit uses the latter.

The response of a feed is fixed to the antenna and thus rotates as seen from the sky with parallactic angle. For short baseline interferometers ($<$100 km) all antennas have essentially the same parallactic angle at all times. Since interferometers measure the differences of signals at individual antennas, the equations relating the feed response to the measured visibilities are degenerate to first order. Traditionally, this degeneracy has been broken by fixing some of the instrumental parameters, giving "relative" solutions.

Wide-band circular polarizers as used for the EVLA have rather large "D terms" allowing for use of higher order terms such as those affecting the parallel hand correlations. Since this requires no instrumental terms to be fixed, it is referred to as "Absolute" calibration. The wide-band polarizers also have frequency structure which needs to be modeled by a spectrum of the feed parameters.

The Obit implementation in task PCal for relative calibration is to fix the orientation of first (RCP) feed of the reference antenna to 0. The "absolute" solution allows this value to be fitted. All correlation products (RR,LL, RL, LR) are used in the fitting and are corrected by the solutions. A non-linear least squares fitting is used in either case. The current best practice for the EVLA is not to fit for a cross-hand delay prior to PCal and using RLPass following PCal to align the R-L phases using the R-L phase calibrator. This allows using weakly polarized calibrators such as 3C48 at low frequencies.

Errors in the instrumental polarization calibration usually result in image artifacts near regions of Stokes I emission. The presence or absence of such artifacts can be used to evaluate the quality of the calibration. More details about instrumental polarization calibration can be found in [4], [1], [2].

III. Example

The following uses the phase and instrumental polarization calibrator from an EVLA S band observation (2-4 GHz). The data were calibrated using the standard Obit calibration pipeline [5], once using a relative instrumental calibration and once using an absolute calibration and otherwise calibrated and imaged the same. 3C286 was used as the flux density and polarization angle calibrator. The instrumental polarization calibrator is very weakly polarized and the instrumental calibration in Obit task PCal fixed the source polarization to zero. A reference antenna of "-1" specified to PCal causes an absolute calibration. Fitting in either case uses a nonlinear least squares solution, the difference being whether any feed parameters were fixed to a nominal value.

The RMS residuals of the absolute fit are typically smaller than those for the relative fit. The absolute solutions converged rapidly whereas the relative solutions had convergence issues. The values of the fitted parameters were also different for the two solutions with the absolute values being generally closer to circular.

After calibration, the source was imaged in I, Q, and U using the Obit wide-band imager MFImage and the source was subjected to a phase self calibration followed by amplitude and phase self calibration. The flux density of the calibrator at the reference frequency (3 GHz) is 1.39 Jy. Figure 1 displays spectra for selected baselines for the polarized calibrator 3C286 with each of the calibrations. The RMS statistics of the derived images are given in Table I. Images of the region around the source are shown in Figure 2.

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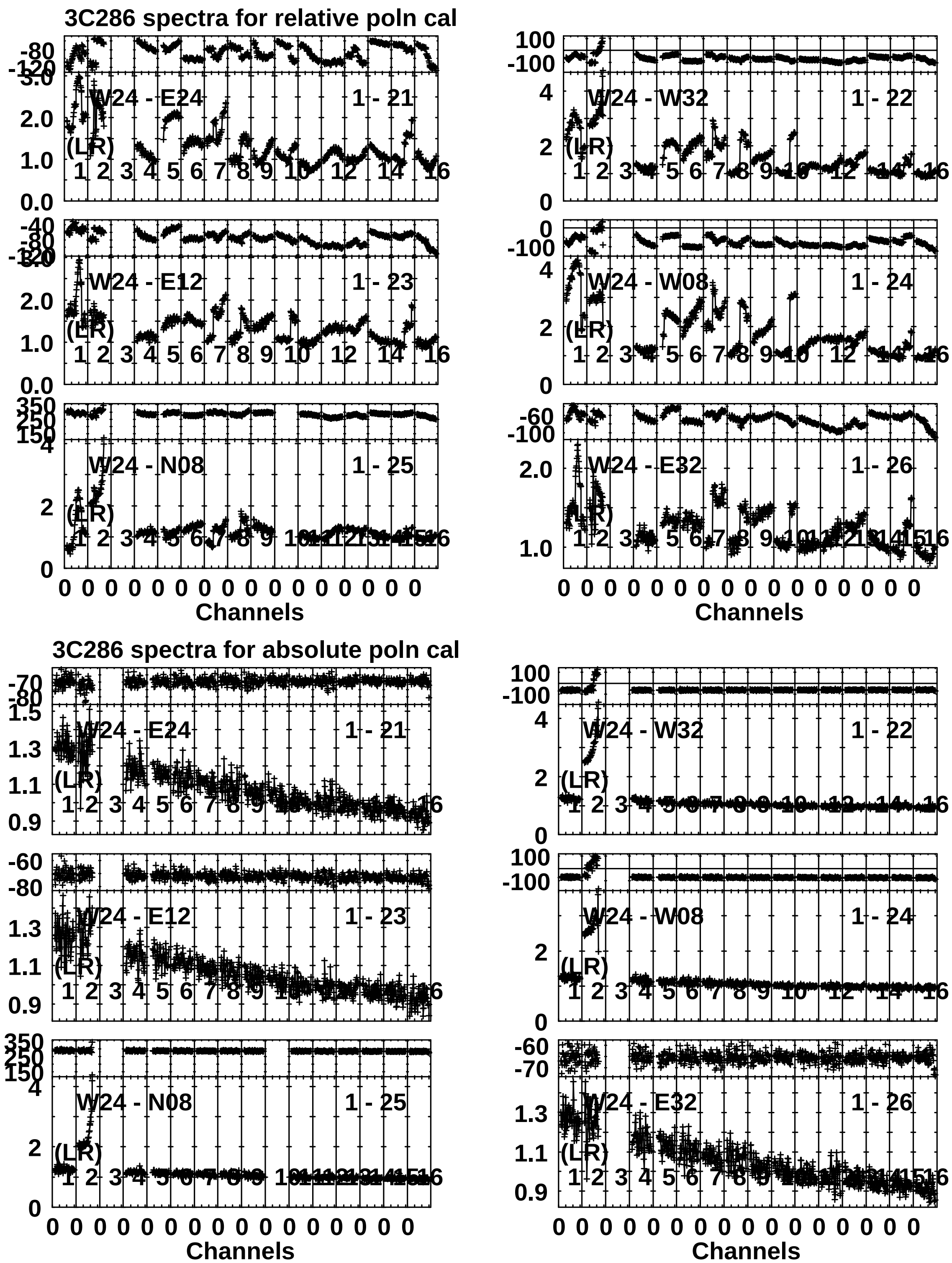

Fig. 1. Calibrated, time averaged spectra in selected baselines for the polarized calibrator 3C286. Upper plot used relative polarization calibration and the lower absolute calibration.

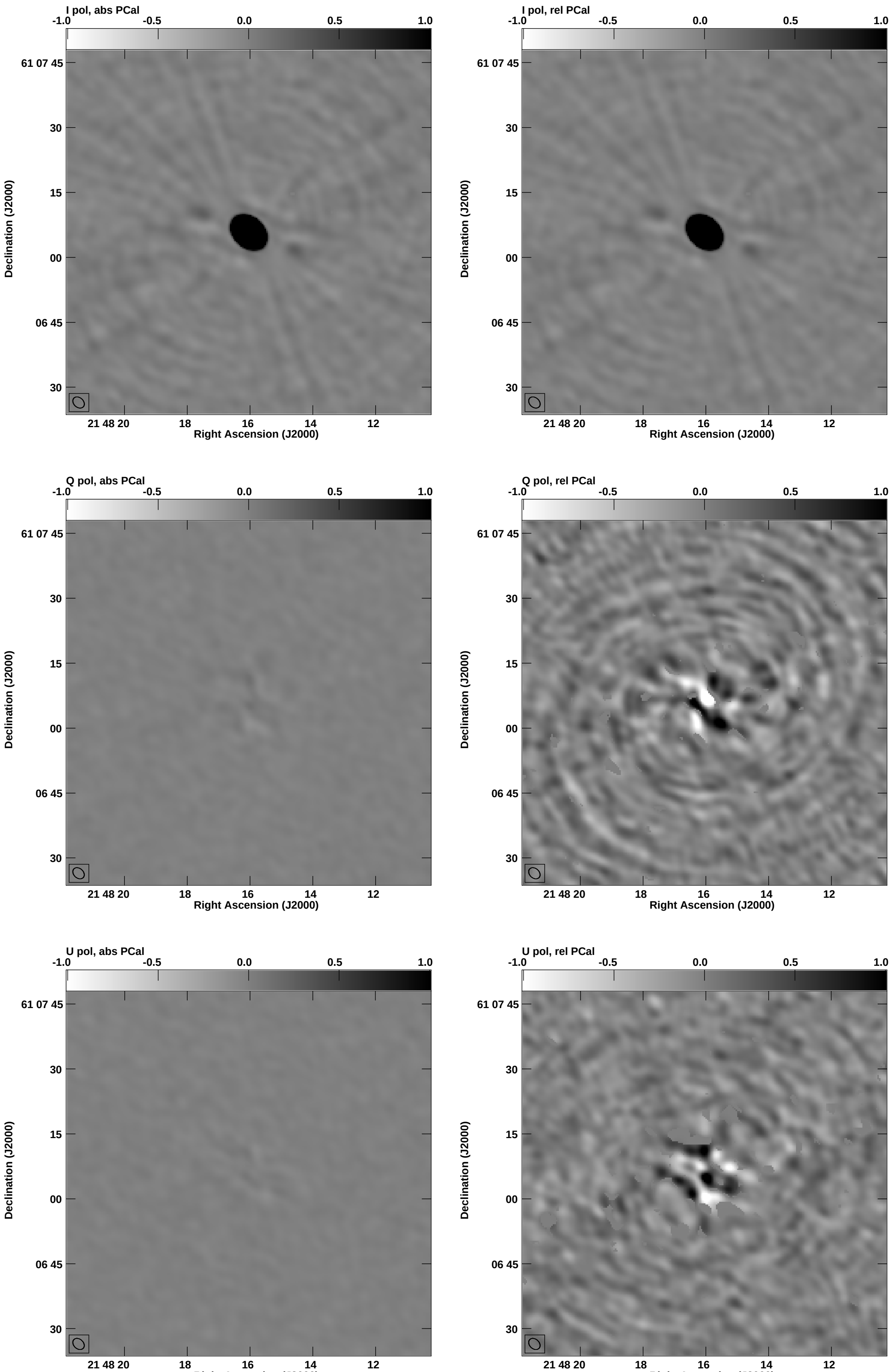

Fig. 2. Negative gray-scale comparison of the Stokes I,Q and U images near a point source calibrated with absolute (left) and relative (right) instrumental polarization calibration. All display a range of +1 mJy/bm to 1 mJy/bm. Peak Stokes I is 1.39 Jy/beam.

IV. Discussion

Table I and Figures 1 and 2 show a dramatic improvement of the absolute calibration over the relative calibration for Stokes Q and U while having very little effect on the Stokes I images. The spectra in Figure 1 for the absolute calibration show a relatively well behaved form except where residual RFI appears. The spectra for the relative calibration show an erratic behavior with frequency. Table I and the plots shown in Figure 2 show a level of artifacts nearly an order of magnitude higher for the relative calibration than for the absolute calibration. The nonlinear fitting in the instrumental polarization calibration task took 51.4 min to run using the relative calibration and 2.8 min for the absolute calibration indicating much more rapid convergence of the absolute solutions. At least in the Obit implementation and using high SNR calibrators, absolute instrumental polarization calibration is clearly preferred; the "relative" calibration seems not to be working as intended.

References

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TABLE I
Imaging RMSes

Calibration	I μJy/bm	Q μJy/bm	U μJy/bm
Relative	40.7	119.	101.
Absolute	40.6	15.0	14.9