EVLA Memo 236
Polarization Properties of Three P-band Calibrators

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Abstract

The meter-wavelength intrinsic polarization properties of DA240, 3C303 and 3C345 have been determined using the VLA's P-band receivers. The ionospheric Faraday rotation has been removed using the ALBUS software.

1 Motivation

A series of EVLA memos (# 207, 210, 219, 226, 230, and 235) has charted our progress in implementing accurate P-band polarimetry using the VLA. The most recent memo (#235) describes our investigation of various IFRM (ionospheric Faraday rotation measure) estimatation programs, and concluded that the ALBUS software package is the best. Here we utilize this package, and five of our P-band lunar observations, to determine the intrinsic polarization properties of three polarized calibrators. Memo #230 included preliminary results for the polarization properties of these low-frequency polarized sources. This memo updates the results.

2 The Observations

The data utilized in this memo are from five VLA P-band observations of the Moon and three known polarized sources. The goals of these observations were to utilize the known lunar polarimetric characteristics of the Moon to complete the implementation of the calibration of linear systems in AIPS, to judge the efficacy of ionospheric Faraday rotation corrections, and to determine the properties of some low frequency polarized calibrators.

Details of the observations used for these results are described in our Memo #235, and will not be repeated here. I have elected to not use the 'D1' observation in this memo, since these data are of considerably worse quality than the remaining five observations.

3 Calibration and Imaging

The VLA P-band receivers are linearly-polarized. Given the considerable advantages of calibration with circular systems, we transformed the linear-based data to circular, using the procedures detailed in EVLA Memo#229. Calibration was then completed using the usual suite of programs.

I summarize here the essential steps in calibrating linearly polarized systems. It is presumed that all flagging corrupted data has been completed.

- FRING and CLCAL, to remove differential delays and phase w.r.t. the reference antenna. The reference antenna chosen here sets the orientation of the EVPA frame. Unfortunately, the JVLA P-band dipoles are known to 'wander' in the orientation, so it is wise to determine in advance an antenna with properly oriented dipoles to use as a phase reference.
- BPASS to solve for the frequency-dependent gains. An unpolarized calibration source is recommended.
- CALIB and CLCAL to solve for the antenna gains. An unpolarized calibration source is required.
- PCAL to solve for cross-polarization leakage. An unpolarized calibration source is required.

- VHDIF, to remove the cross-hand phase. A strongly polarized calibration source is required. The polarization state of this source does not need to be known.

In principle, this is sufficient for imaging the data, once the IFRM correction step, described below, is completed. However, the requirement to utilize unpolarized sources in the gain calibration is restricting – calibrators near to the target source cannot be utilized unless it is known that they have negligible polarization[1]. In order to utilize all calibrators without having to know their polarization states, it is recommended to convert to a circular basis, and then complete the calibration. These are the steps:

- VH2RL, to convert the linear-basis data to circular-basis. The gain calibration steps summarized above must be applied.
- FRING, CLCAL, BPASS, CALIB, CLCAL, and PCAL can all be executedn in the standard way. As noted above, the restriction to unpolarized calibrators is removed. Because these data have been 'pre-calibrated' by the preceding steps, all complex gain results should be near 1.0.
- ALBUS, to estimate the ionospheric Faraday rotation measure (IFRM). An alternative program, TECOR, can also be utilized, but as we have shown in memo #235, this gives inferior results.

Note that the programs RLDLY and RLDIF, normally utilized for circular-polarized system calibration, are not required here, as the rotation frame has been set by the reference antenna selected in the linear-polarization calibration, and the cross-hand phases and delays have been removed by the VHDIF operation.

As noted in Memo#235, there are two versions of 'ALBUS' available – one which uses a limited set of GNSS station data, and another which utilizes a much larger set. Contrary to simple expectation, the 'limited' set usually gives better predictions of the IFRM. For this memo, I used the version of ALBUS which most closely matched the lunar observation IFRM determinations.

Although I am confident that ALBUS removes the changing IFRM due to day-night effects correctly, out of an abundance of caution, the measurements used in this memo used only those data taken at night, during calm ionospheric conditions.

4 Results

Here I give brief summaries of the results for each of the three sources.

4.1 DA240 West Hotspot

DA240 is a nearby radio galaxy with an unusually bright and highly polarized hotspot in its eastern lobe. An image with 46 arcseconds resolution at 424 MHz, using data from five VLA P-band observations, showing the observed polarization, is shown in Fig 1. The source is very extended – spanning about 30 arcminutes. The prominent hotspot in the eastern lobe is is partially resolved. This hotspot is a very good low-frequency polarization calibrator for the VLA's C and D configurations as the polarized flux density exceeds 400 mJy.

The observed polarization EVPAs for DA240 are shown in Fig 1. The different observations are plotted with different colors, as shown in the figure legend. The red (dashed) line is the linear fit to the average of all five observations. The data show a nearly perfect λ^2 relation, indicating that the slope represents the RM associated with the host galaxy and our own galaxy. There is no sign of non-linear behavior. The fractional polarization is ~ 15 to 20%, depending on resolution, with the higher fraction associated with higher resolution. All five observations give very similar results, with a maximum spread of about 0.1 rad/m^2 in IFRM, and six degrees in intrinsic angle.

The best-fit, global average RM is 3.02 ± 0.02 rad/m^2 – within 1-σ of the WSRT value determined by Michiel Brentjens in his thesis. The determined intrinsic EVPA at $\lambda = 0$ is 60 ± 1 degrees, which places the B-vector about orthogonal to the line joining the hotspot to the nucleus, as expected for structure of this type.

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[1] This is usually true at P-band, but not at any higher-frequency band. This restriction can be removed if the polarization state, as a function of frequency, is known in advance, or can be determined from the observations – however, for P-band observations, the effects of Faraday rotation must be removed before such data can be utilized.

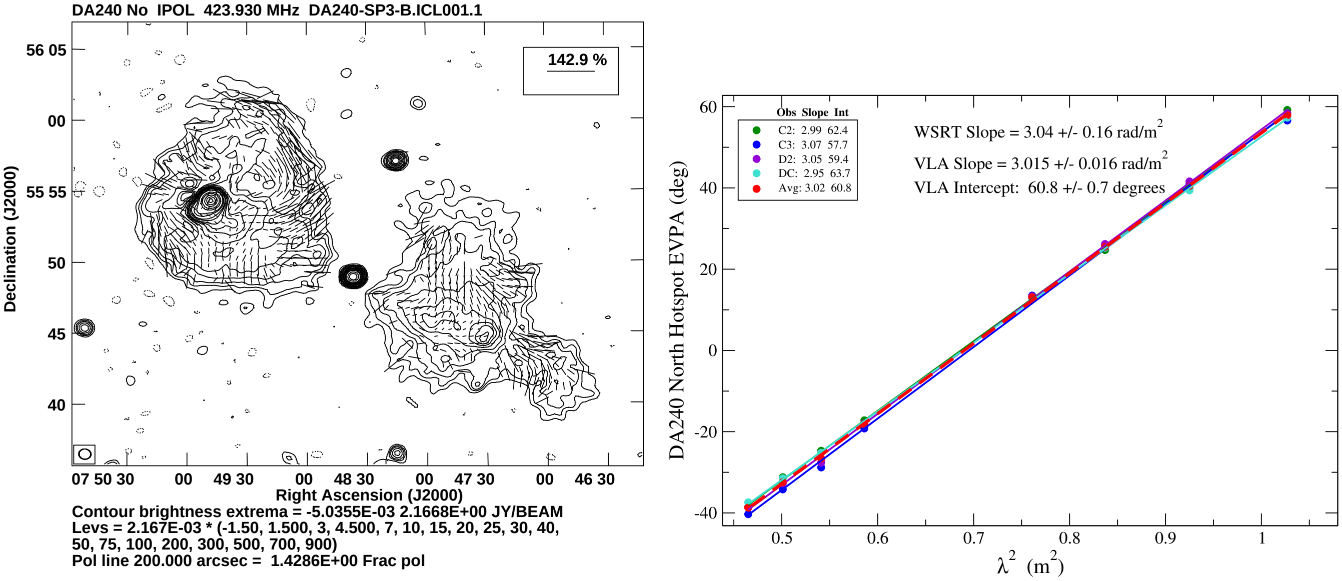

Figure 1: **Left Panel** The structure and polarization DA240 at 424 MHz with 46 arcseconds resolution, utilizing the data taken from five P-band observations taken in the 'C' and 'D' configurations. **Right Panel** The corrected EVPAs for the DA240 northern hotspot, for each of the five observations.

4.2 3C303 West Hotspot

The Seyfert galaxy 3C303 has a very prominent, highly polarized hotspot, which makes it a prime candidate for a polarization calibrator. The source was observed on two dates. No image is shown here, as the 47 arcsecond extent is barely resolved to the VLA in C configuration. The determined EVPA, after correction for the IFRM, is shown in the left panel of Fig 2. The hotspot is 5.1% polarized (corresponding to ∼300 mJy polarized flux) at 424 MHz.

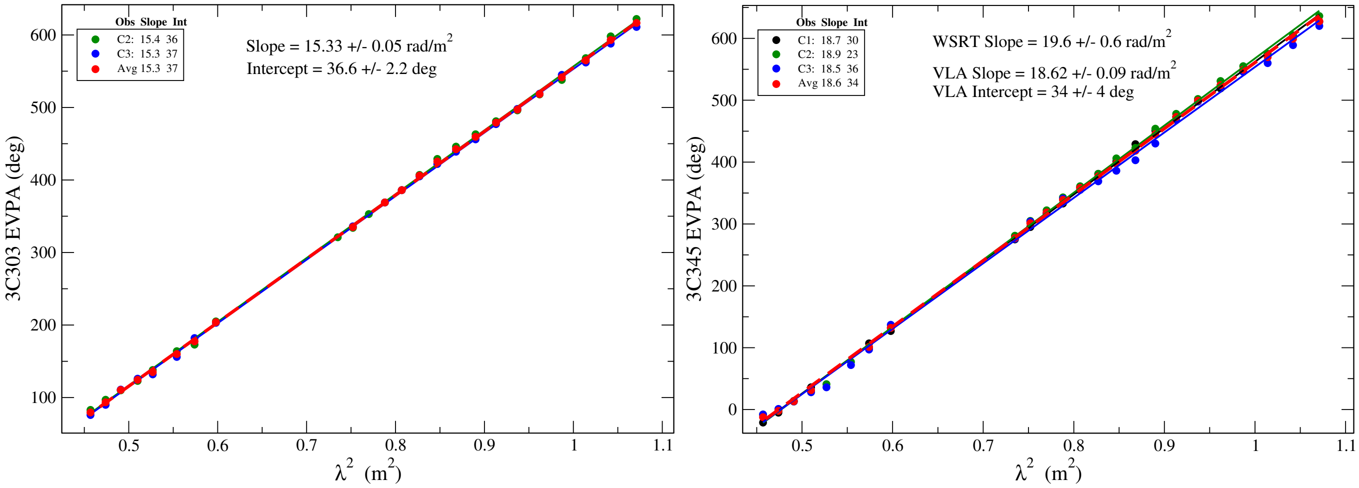

Figure 2: **Left** The fit of IFRM-corrected EVPA of 3C303 against λ^2. As with the other sources, a very clean linear fit is found. **Right** The fit for the IFRM-corrected EVPAs for 3C345.

The excellent linear fit provides the source RM and intrinsic position angle solutions shown in the figure. There is no WSRT measurement to compare these results to.

4.3 3C345 = J1642+3948

3C345 is a well known quasar, with a jet and bright hotspot extending to the NE some 3 arcseconds from the nucleus, embedded in a more extensive structure most prominent at low frequencies. It is only slightly resolved in our 45-arcsecond resolution images. The polarized emission – likely from the hotspot – is only 3.3% of the total flux, making this source somewhat marginal as a polarization calibrator. It was observed three times in our program, and the resulting EVPAs are shown in Fig 2. The derived RM is 18.6 ± 0.1 rad/m^2, which is to be compared to the WSRT-determined value of 19.6± 0.6 rad/m^2.

The three fits shown here have much greater scatter between them than either the DA240 or 3C303 results. This could be due either to the lower fractional polarization (which enhances the errors from incorrect D-term determinations), or from variability in the source – the potentially polarized variable nucleus, and the polarized hotspot at the tip of the jet undergoing destructive interference.

5 Summary

In principle, linearly-polarized receiver systems do not require a source of known EVPA for calibration. However, it is useful to have such sources available, in order to compare results from a given observation. This is particularly the case for low-frequency observations, where the variable ionosphere causes significant rotation of the observed plane of polarization. The three sources whose intrinsic properties are shown here should serve this purpose.

For two of these sources – DA240 and 3C303 – it is certain that the dominant polarization originates from 'hotspots' at the outer boundaries of the observed emission. For 3C345, the polarized emission is likely to originate from the jet, although higher-resolution observations will be needed to confirm this. The advantage of using radio galaxy or quasar hotspots for low-frequency polarimetry calbration arises from their optically thin synchrotron emission – the fractional polarization and the intrinsic EVPA is the same over all frequencies, – and from their locations well outside the central cores of the associated galaxy. These offset locations should greatly reduce any differential ('beam') depolarization due to intervening galactic gas and reduce the total rotation measure.

As noted, the hotspots in DA240 and 3C303 are slightly resolved at the resolution of these observations. The polarization of 3C345 is suspected to arise from its jet termination, but this cannot be confirmed with the data in hand. In order to answer these remaining issues, We plan to make observations early in 2025, in the 'A' configuration.