VLASS Project Memo 6

Compactness of 3C 48, 3C 138, and 3C 286 at 2–4 GHz

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In this document the observed compactness of the primary flux and polarization angle calibrators 3C 48, 3C 138, and 3C 286 is evaluated for the VLASS observation frequencies of 2 – 4 GHz in the VLA B-configuration.

1 Observation

A number of primary flux density and polarization calibrators were observed together with 3C 48, 3C 138, and 3C 286 on August 20, 2016 under TSKY0001 project code with scheduling block id 32534953. The VLA was in B configuration at that time. The frequency setup was that of VLASS, 16 spectral windows with 64 channels each and 2 MHz bandwidth per channel from 1.965 to 4.011 GHz. The data was reduced with the VLASS calibration pipeline for casa 4.7.0-1. The instrumental polarization was determined using one scan on J0319+4130, the flux density and polarization angle were calibrated using 3C 286.

2 Compactness

The compactness of each calibrator is evaluated by differencing and dividing a point source model from their visibilities per spectral window. This is performed using the AIPS tasks `EVAUV`. The deviation from a point source is then noted by deviating residual amplitudes from the expected values of 0 or 1 respectively, depending on whether the visibilities were differenced or divided by the point source model. To simplify comparison the divided values are subtracted by 1.0 in the following tabulations.

2.1 Stokes I point-source model

2.1.1 J0739+0137

The calibrator J0739+0137 has an observed S-band flux density of about 1 Jy and is considered point like in B configuration at S-band. The VLA Calibrator manual flag is listed as 'P' for both L and C band in all configurations. The AIPS task `EVAUV` plots the real against the imaginary amplitudes for both dividing and subtracting a point source model. The resulting plots are shown in Fig. 1. If the source were removed perfectly, one would only expect values close to 0, with a spread of values due to residual noise and residual structure. The concentric circles seen in Fig. 1 are an artefact of the plotting routine, however the largest scale of the ring is around 0.5, indicating residual spectral structure that was not removed by the monochromatic point source model. However, statistically the mean subtracted and divided values are close to 0 as expected. Table 1 lists the derived values across most spectral windows between 2.0 and 4.0 GHz. This verifies J0739+0137 is indeed a point-like source and a good calibrator target. The residual amplitudes are rather high with a median value of ∼23%.

2.1.2 3C 48

For 3C 48 there is residual phase structure which can be seen in Fig. 2 as 'ears' around the close to circular offset concentric circles. This indicates that 3C 48 is slightly resolved at S-band in B configuration. The residual median flux for subtracting a point source model is 7.2%. 3C 48 has a fractional linear polarization of 2.3%. The residual resolved polarized flux density is 11–19 mJy and not accounted for by the point model introducing an overall error of 0.09 – 0.3%. The actual derived values for both division and subtraction of a point source model for 3C 48 are given in Table 2.

2.1.3 3C 138

Similar to 3C 48, the calibrator source 3C 138 is slightly resolved (see Fig. 3). The median resolved flux corresponds to about 6% of the source model flux density. Thus at an intrinisc linear polarization fraction of 10.7%, the resolved linear polarized flux density is of the order 29–44 mJy which corresponds to an overall polarization fraction error of ∼0.6%. The actual derived values for both division and subtraction of a point source model for 3C 138 are given in Table 3.

2.1.4 3C 286

Similar to 3C 48, the calibrator source 3C 286 is slightly resolved (see Fig. 4). The median resolved flux corresponds to about 18% of the source model flux density. Thus at an intrinisc linear polarization fraction of 11%, the resolved linear polarized flux density is of the order 149–236 mJy, which corresponds to an overall polarization fraction error of ∼2.0%. The actual derived values for both division and subtraction of a point source model for 3C 286 are given in Table 4.

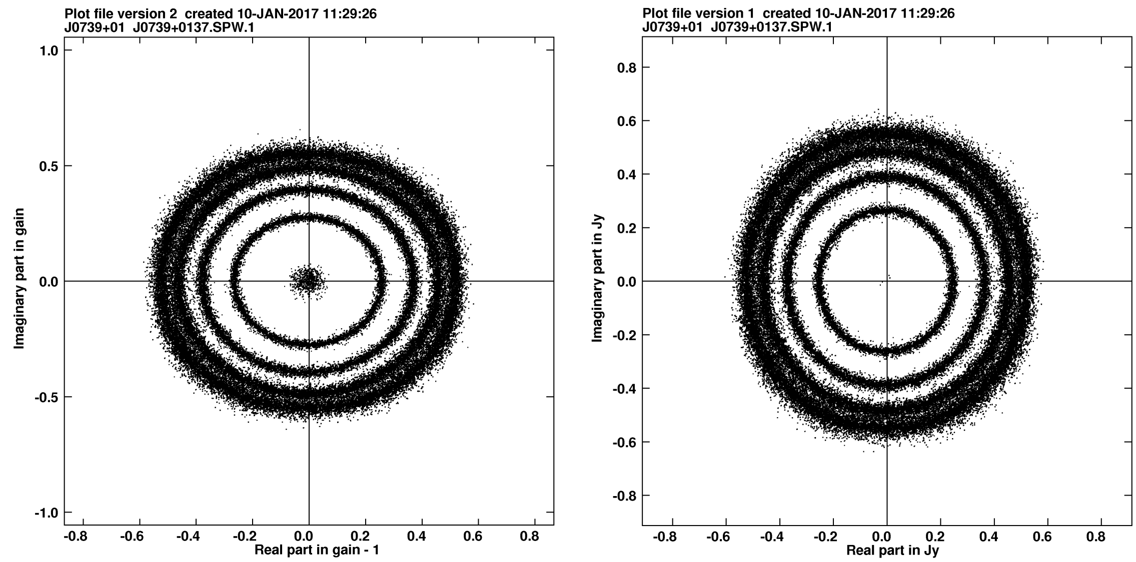

Figure 1: *Left:* Real vs. imaginary amplitudes after dividing a 1 Jy point source model at the phase center. *Right:* Real vs. imaginary amplitudes after subtracting a 1 Jy point source model at the phase center. The data shown is for a 128 MHz bandwidth of J0739+0137 with the spectral window centered at 2.9 GHz.

Table 1: Residual amplitudes after division or subtraction of a point source model with given Stokes I flux density for J0739+0137.

SPW	**I Flux**	**Model Divided**			**Model Subtracted**		
	(Jy)	Real	Imag.	Amp.	Real	Imag.	Amp.
2	1.012	0.0031	0.0003	0.2248	0.0032	0.0003	0.2275
5	1.007	0.0029	0.0006	0.2362	0.0029	0.0006	0.2362
6	1.008	0.0023	0.0007	0.2312	0.0023	0.0007	0.2312
7	1.007	0.0019	0.0008	0.2295	0.0019	0.0008	0.2311
8	1.007	0.0006	0.0008	0.2343	0.0006	0.0008	0.2359
9	1.011	-0.0043	0.0008	0.2187	-0.0043	0.0008	0.2211
10	1.004	0.0017	0.0008	0.207	0.0017	0.0008	0.2078
11	1.006	-0.0013	0.0009	0.1984	-0.0013	0.0009	0.1996
12	1.01	-0.0061	0.0009	0.1916	-0.0061	0.0009	0.1935
13	1.002	0.0005	0.0007	0.1935	0.0005	0.0007	0.1939
14	1.009	-0.0072	0.0017	0.1986	-0.0073	0.0018	0.2004
15	1.019	-0.0177	0.0001	0.2557	-0.018	0.0001	0.2606
16	0.936	0.1035	-0.0055	0.4686	0.0969	-0.0051	0.436
17	0.993	0.0474	-0.0037	0.3977	0.0471	-0.0037	0.395

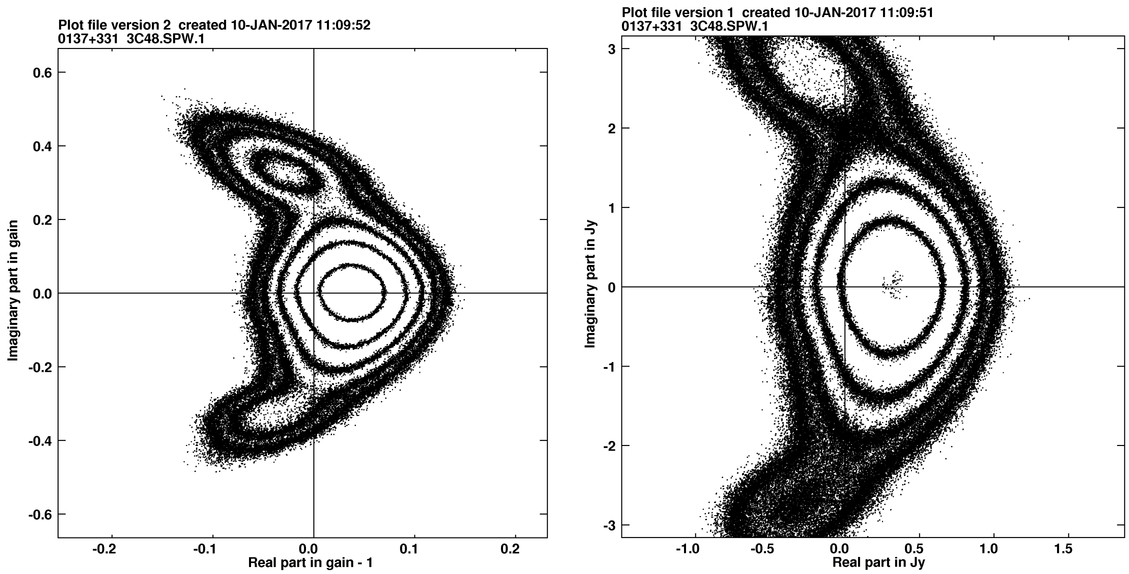

Figure 2: *Left:* Real vs. imaginary amplitudes after dividing a 8.3 Jy point source model at the phase center. *Right:* Real vs. imaginary amplitudes after subtracting a 8.3 Jy point source model at the phase center. The data shown is for a 128 MHz bandwidth of 3C 48 with the spectral window centered at 2.9 GHz.

Table 2: Residual amplitudes after division or subtraction of a point source model with given Stokes I flux density for 3C 48.

SPW	**I Flux**	**Model Divided**			**Model Subtracted**		
	(Jy)	Real	Imag.	Amp.	Real	Imag.	Amp.
2	11.634	0.0282	-0.0013	0.0603	0.328	-0.0151	0.7011
3	11.247	0.0048	0.0012	0.0514	0.054	0.0135	0.5781
5	10.103	0.0175	-0.0014	0.0638	0.1772	-0.014	0.6448
6	9.513	0.0282	-0.0013	0.0701	0.2681	-0.0124	0.6669
7	9.136	0.0241	-0.0018	0.0692	0.2201	-0.0163	0.6324
8	8.742	0.025	-0.0018	0.0722	0.2186	-0.0157	0.6311
9	8.299	0.0358	-0.0016	0.0787	0.2969	-0.0135	0.6528
10	7.951	0.0383	-0.0019	0.082	0.3042	-0.0153	0.6519
11	7.796	0.0188	-0.002	0.0748	0.1466	-0.0156	0.583
12	7.354	0.0403	-0.0019	0.0872	0.2961	-0.0139	0.6416
13	7.007	0.0529	-0.002	0.0963	0.3709	-0.0144	0.6751
14	6.912	0.0304	-0.0021	0.0855	0.2099	-0.0147	0.591
15	6.756	0.0189	-0.002	0.085	0.1274	-0.0137	0.5743
16	6.658	0.0001	-0.0024	0.0621	0.0005	-0.0159	0.4135
17	6.487	-0.006	-0.0025	0.0625	-0.0388	-0.0159	0.4053

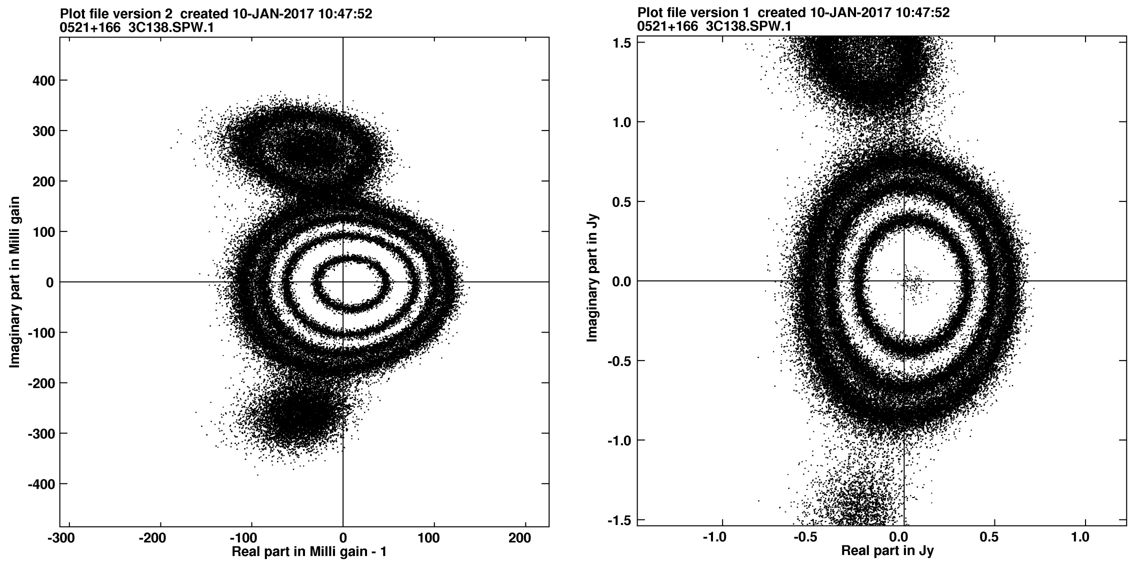

Figure 3: *Left:* Real vs. imaginary amplitudes after dividing a 5.5 Jy point source model at the phase center. *Right:* Real vs. imaginary amplitudes after subtracting a 5.5 Jy point source model at the phase center. The data shown is for a 128 MHz bandwidth of 3C 138 with the spectral window centered at 2.9 GHz.

Table 3: Residual amplitudes after division or subtraction of a point source model with given Stokes I flux density for 3C 138.

SPW	**I Flux**	**Model Divided**			**Model Subtracted**		
	(Jy)	Real	Imag.	Amp.	Real	Imag.	Amp.
2	6.921	0.0221	-0.0031	0.0559	0.1533	-0.0211	0.3872
3	6.661	0.0197	0.0027	0.0615	0.1311	0.0181	0.4096
5	6.257	0.0082	-0.0048	0.0563	0.0512	-0.0302	0.3525
6	6.0	0.0142	-0.0044	0.0611	0.085	-0.0264	0.3668
7	5.849	0.0082	-0.0049	0.0584	0.0482	-0.0288	0.3416
8	5.665	0.0086	-0.0055	0.0615	0.0489	-0.0313	0.3481
9	5.516	0.0058	-0.0053	0.0598	0.0319	-0.029	0.33
10	5.336	0.0099	-0.0064	0.0607	0.053	-0.0342	0.3237
11	5.184	0.0117	-0.0067	0.0618	0.0607	-0.0347	0.3204
12	5.067	0.0077	-0.0072	0.0619	0.0392	-0.0367	0.3138
13	4.887	0.0182	-0.007	0.0653	0.0889	-0.0341	0.3193
14	4.804	0.0107	-0.0072	0.0644	0.0514	-0.0344	0.3094
15	4.662	0.0148	-0.0074	0.0733	0.0692	-0.0344	0.3417
16	4.667	-0.0119	-0.005	0.0819	-0.0554	-0.0233	0.3821
17	4.572	-0.0102	-0.0046	0.0744	-0.0465	-0.0211	0.3402

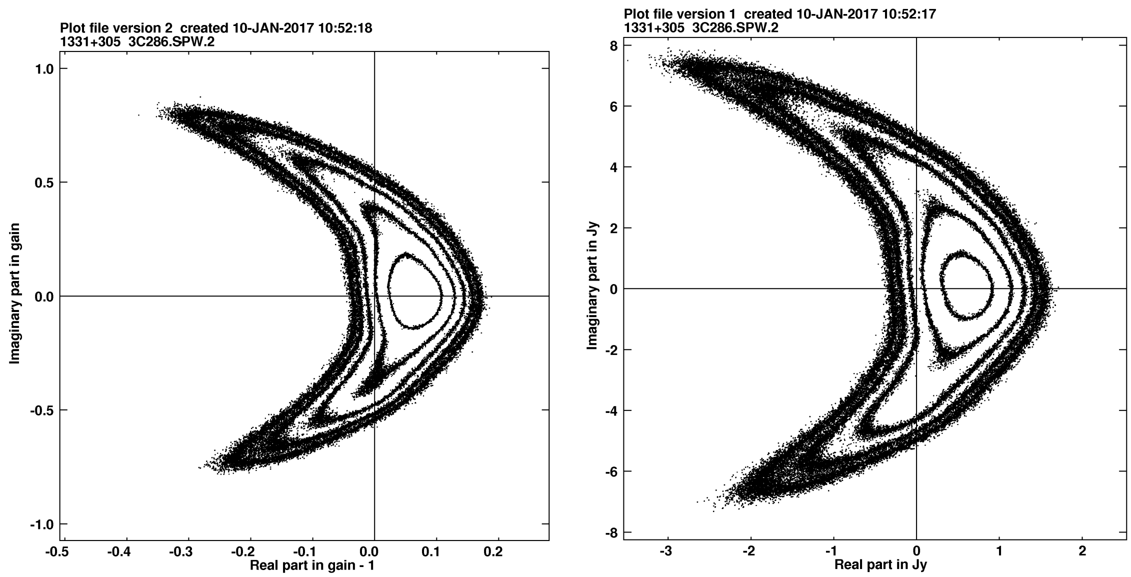

Figure 4: *Left:* Real vs. imaginary amplitudes after dividing a 9.3 Jy point source model at the phase center. *Right:* Real vs. imaginary amplitudes after subtracting a 9.3 Jy point source model at the phase center. The data shown is for a 128 MHz bandwidth of 3C 286 with the spectral window centered at 2.9 GHz.

Table 4: Residual amplitudes after division or subtraction of a point source model with given Stokes I flux density for 3C 286.

SPW	**I Flux** (Jy)	**Model Divided** Real	**Model Divided** Imag.	**Model Divided** Amp.	**Model Subtracted** Real	**Model Subtracted** Imag.	**Model Subtracted** Amp.
2	11.908	0.0312	0.0095	0.1218	0.3715	0.1127	1.4502
3	11.572	0.0249	-0.0106	0.118	0.2877	-0.1231	1.3649
5	10.703	0.0304	0.0108	0.1461	0.3259	0.116	1.5642
6	10.328	0.0339	0.0106	0.1471	0.03497	0.1095	1.5196
7	10.031	0.0325	0.011	0.1511	0.3259	0.1103	1.5152
8	9.702	0.0358	0.0109	0.1586	0.3474	0.1057	1.4663
9	9.322	0.0482	0.0108	0.1694	0.4493	0.1008	1.5789
10	8.937	0.0624	0.011	0.1838	0.5573	0.0984	1.643
11	8.763	0.0549	0.0117	0.1858	0.4813	0.1027	1.6286
12	8.391	0.0742	0.0113	0.2028	0.6225	0.095	1.7017
13	8.26	0.0638	0.0122	0.2015	0.5271	0.1011	1.6648
14	7.892	0.0876	0.0124	0.2235	0.6914	0.098	1.7637
15	7.902	0.0578	0.012	0.2177	0.4569	0.0952	1.7199
16	7.612	0.0753	0.0154	0.2379	0.5731	0.117	1.8107
17	7.524	0.065	0.0155	0.2379	0.4892	0.1163	1.79

2.2 Stokes I clean-components

Instead of subtracting/dividing a point-source model, a Stokes I clean-component model was obtained from Rick Perley for 3C 48, 3C 138, and 3C 286 all for a center frequency of 2.947 GHz (averaged over 92 MHz of bandwidth) and for VLA A configuration. The resulting residual real and imaginary parts are plotted against each other for 3C 48 (Fig. 5), 3C 138 (Fig. 6), and 3C 286 (Fig. 7). Also the resulting statistical parameters are tabulated for all three sources in Table 5.

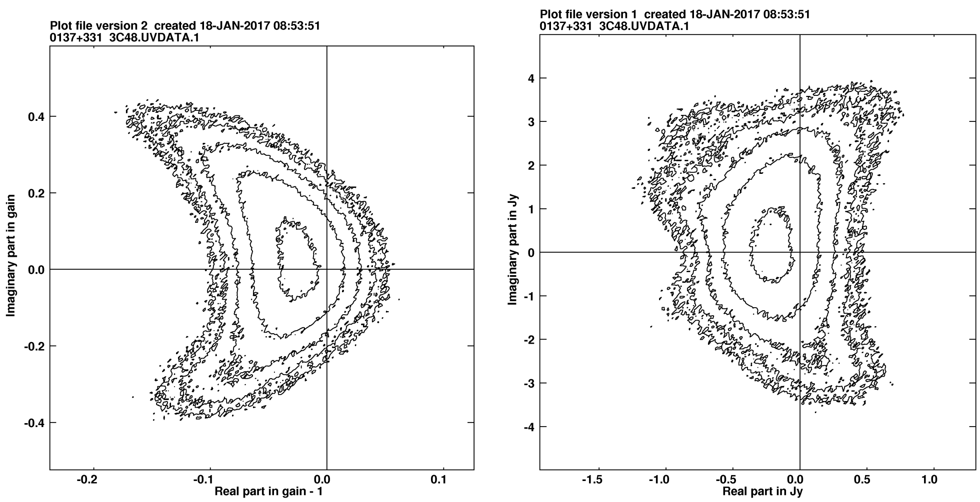

Figure 5: *Left:* Real vs. imaginary amplitudes after dividing a Stokes I clean component model. *Right:* Real vs. imaginary amplitudes after subtracting a Stokes I clean component model. The data shown is for a 6 MHz bandwidth of 3C 48 with the spectral window centered at 2.947 GHz.

Table 5: Residual amplitudes after division and subtraction of a Stokes I clean component model at 2.947 GHz for 3C 48, 3C 138, and 3C 286.

Target	**I Flux**	**Model Divided**			**Model Subtracted**		
	(Jy)	Real	Imag.	Amp.	Real	Imag.	Amp.
3C 48	8.80	-0.0341	0.0303	0.1141	-0.1852	0.2709	1.0055
3C 138	5.62	-0.0178	0.007	0.1008	-0.0378	0.0383	0.5678
3C 286	10.3	-0.0443	0.0088	0.1432	-0.4575	0.0924	1.4597

2.3 Stokes Q/U

For polarization calibration, the polarized emission is centered at the phase center in the case of 3C 286. The extended emission from 3C 286 is mostly unpolarized, as well as the

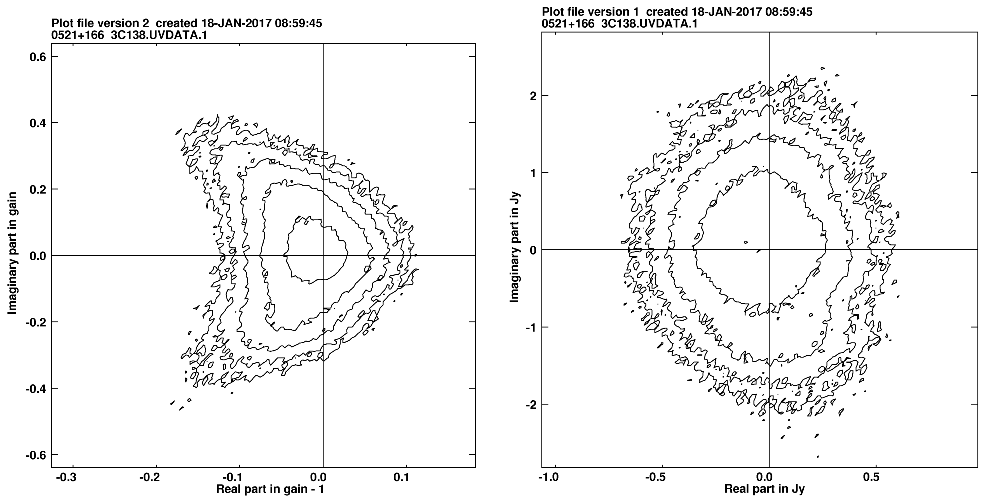

Figure 6: *Left:* Real vs. imaginary amplitudes after dividing a Stokes I clean component model. *Right:* Real vs. imaginary amplitudes after subtracting a Stokes I clean component model. The data shown is for a 6 MHz bandwidth of 3C 138 with the spectral window centered at 2.947 GHz.

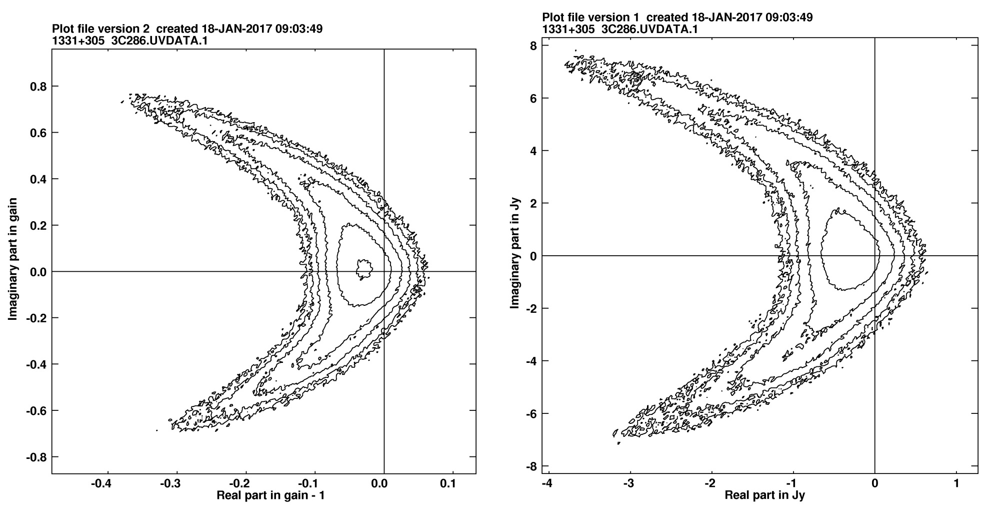

Figure 7: *Left:* Real vs. imaginary amplitudes after dividing a Stokes I clean component model. *Right:* Real vs. imaginary amplitudes after subtracting a Stokes I clean component model. The data shown is for a 6 MHz bandwidth of 3C 286 with the spectral window centered at 2.947 GHz.

three nearby background sources (Cotton et al., 1997), thus the error for polarization calibration is expected to be small if using a point-source model. However in the case of 3C 48 the peak of the polarized emission is offset by 0.25 arcsec North of the core (An et al., 2010). In B configuration the synthesized beam at 3.0 GHz is 2.1 arcsec. For a bright source like 3C 48 this offset could affect polarization calibration if a point-source model is used at the phase center. Currently, the CASA task `setjy` does not allow placement of a point-source model other than at the phase center.

Similar to the previous discussed analysis for Stokes I, an analysis was performed for Stokes Q and U in the case of 3C 48 and 3C 286 using the AIPS task `EVAUV`. In both cases 3C 286 and 3C 48 the residuals are indistinguishable between using clean components provide by Rick Perley at 2.947 GHz and that of a point source centered at the phase center.

3 Summary & Conclusions

The primary flux density calibrators 3C 48 and 3C 286 that will be used for the VLASS are slightly resolved in B-configuration between 2.0 and 4.0 GHz. The missing Stokes I flux density is up to 7.2% of the total flux in the case of 3C 48 and up to 18% in the case of 3C 286 when a point-source model is used. To minimize these errors, model images have to be derived for the primary flux and polarization angle calibrators that include sufficient spectral resolution to cover spectral variations at the few % level and include maps for Stokes I, Q, and U.

Derived clean-component maps were used for 3C 48, 3C 138, and 3C 286 to demonstrate the improvement when a clean-component model is used. For 3C 48 and 3C 138 the improvements are significant when comparing the residual phase structures. However, in the case of 3C 286 the improvement is marginal. This is most likely due to three nearby unpolarized background sources that are not accounted for in the model image.

It was determined that for Stokes Q and U a point-source model is adequate for describing the polarized emission of both 3C 48 and 3C 286. Thus, only for flux density calibration it is deemed necessary to use a clean components model for accurate calibration, while for polarization calibration a point-source model at the phase center suffices.

References

An, T., Hong, X. Y., Hardcastle, M. J., et al. 2010, MNRAS, 402, 87

Cotton, W. D., Fanti, C., Fanti, R., et al. 1997, A&A, 325, 479

Revision History

Revision	Date	Author(s)	Description
0.1	2016-01-10	Frank Schinzel	first complete draft
0.2	2016-01-18	Frank Schinzel	added clean-component discussion
1.0	2016-01-18	Frank Schinzel	finalized and added Q/U discussion