

Recent ALMA Polarization Commissioning Results and Remaining Questions

Hiroshi Nagai

(NAOJ EA-ARC / JAO System Verification Team)

Polarization Team

JAO CSV team

- Observation mode
- Science verification
- etc

E. Fomalont
K. Nakanishi

JAO SysVer team

- Test the ALMA system technical requirement

H. Nagai

CASA team

- Development of polarization calibration task

G. Moellenbrock

External Member

E. Chapillon, Y.-W. Tang (EA)
: ARC “in-kind” contribution

ALMA Specification

Polarized
flux error

The error in polarized flux for a source where the circularly and linearly polarized fluxes are zero shall be no more than 0.1% of the total intensity on axis after calibration.

Polarization
position
angle

It shall be possible to determine the position angle of linearly polarized flux density to 6°.

Basic Equation

$$\hat{V}_{X_m} \hat{V}_{X_n}^* = I + Q \cos(2\psi_m) + U \sin(2\psi_m)$$

$$\hat{V}_{Y_m} \hat{V}_{Y_n}^* = I - Q \cos(2\psi_m) - U \sin(2\psi_m)$$

$$\hat{V}_{X_m} \hat{V}_{Y_n}^* = I(D_{X_m} + D_{Y_n}^*) - Q \sin(2\psi_m) + U \cos(2\psi_m) + iV$$

$$\hat{V}_{Y_m} \hat{V}_{X_n}^* = I(D_{Y_m} + D_{X_n}^*) - Q \sin(2\psi_m) + U \cos(2\psi_m) - iV$$

(D^2 , D^*Q , D^*U , D^*V neglected)

- D-term calibration is the most critical part of polarization observation

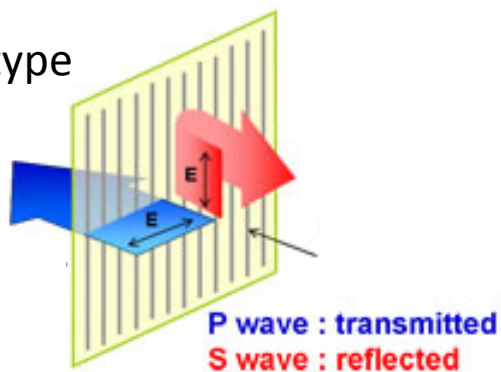
Polarization Leakage D-term

Instrument	Typical D-term level	reference
VLA	<5%	www.aoc.nrao.edu/~gtaylor/calman/polcal.html
VLBA	1-7%	VLBA Scientific Memo #30
SMA	1-5%	D. Marrone's PhD thesis

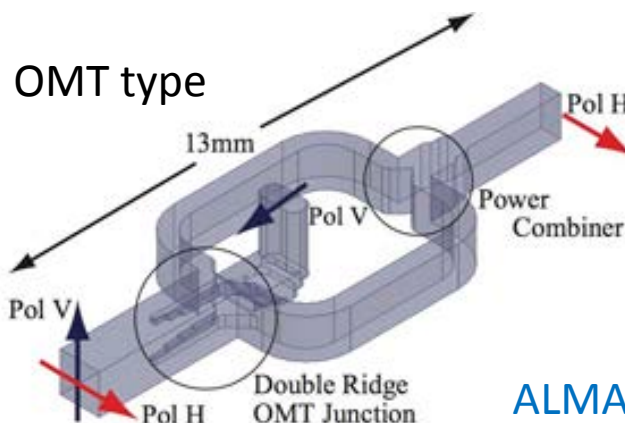
Even if the system is designed very well, D-term can be ~5%.

- Primary reason: polarization separation at frontend

Wire grid type



ALMA B7/9/10



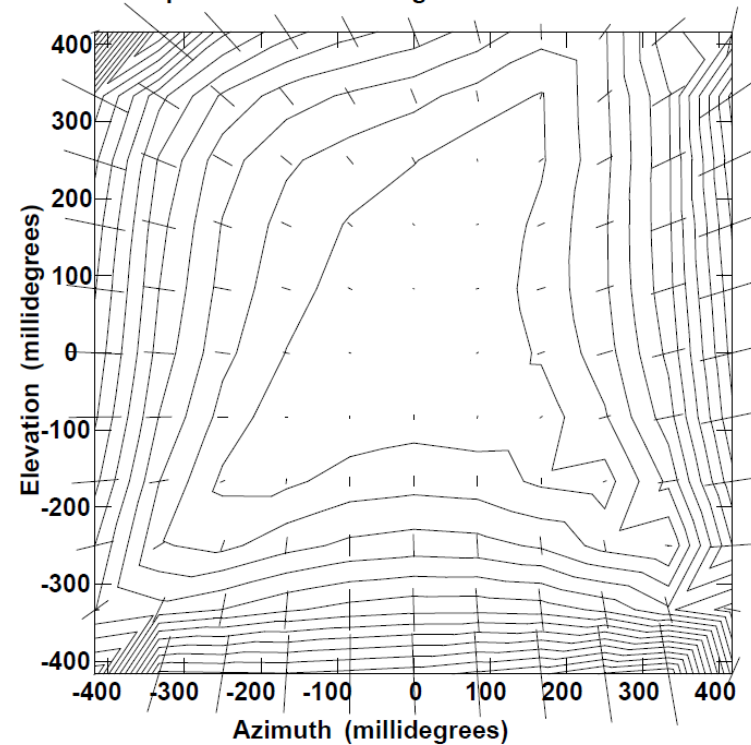
Osaka Prefecture Univ.

ALMA B3/6/8

Direction dependence $D(\theta)$

Off-axis instrumental polarization (VLA)

08 September 1994 average of 6 scans



AIPS memo #86 (W. Cotton)

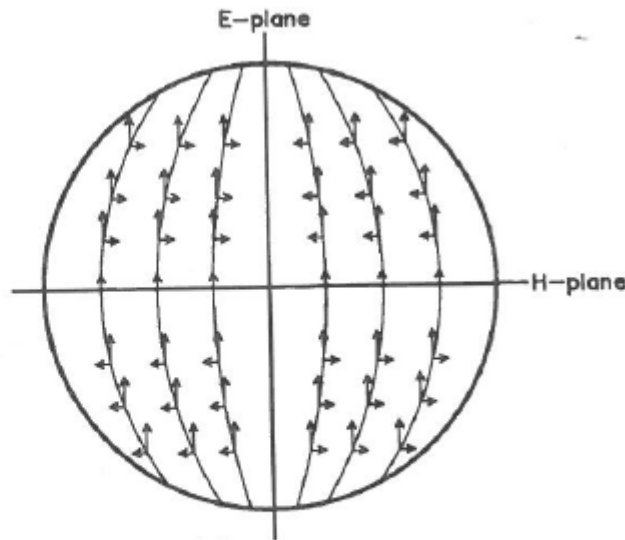


Figure 3-13. Field distribution in the aperture of a paraboloid fed by an electric dipole. The field is resolved into its co- and cross-polarized components.

P. Napier

- Reflection $\rightarrow$ Xpol $\Leftrightarrow$ Ypol
- D will vary across the primary beam (off-axis D)
 - Removal of this effect is necessary for accurate wide-field polarization imaging



Commissioning items, so far

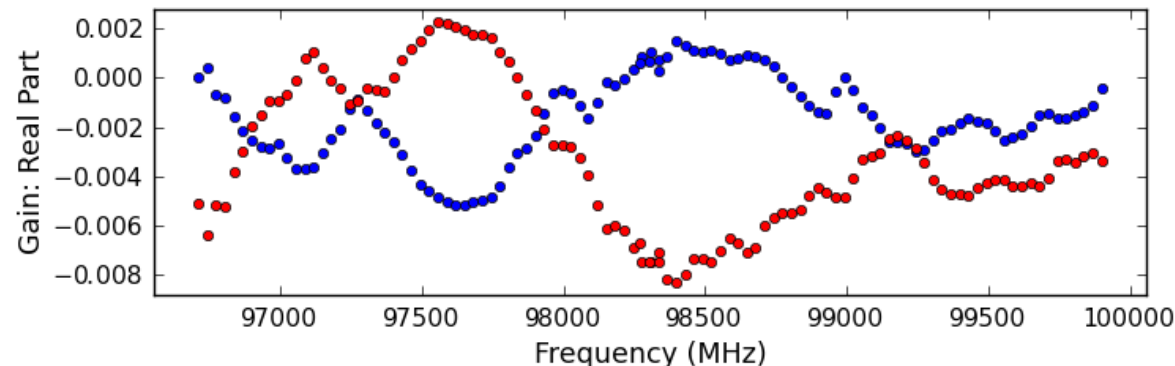


1. On-axis D level, frequency structure
2. On-axis D Stability
3. Direction dependence of D (off-axis)

Band 3 On-axis D-term

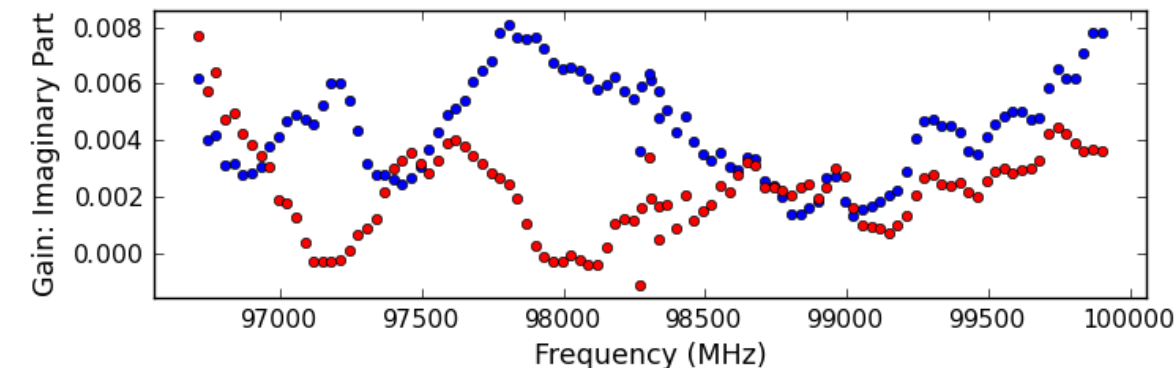
DV04

D table: 1924_B3_AUG18.concat.ms.split.Df0sky



- Typically 1-3%
- Frequency structure $\pm 0.5\%$

D table: 1924_B3_AUG18.concat.ms.split.Df0sky



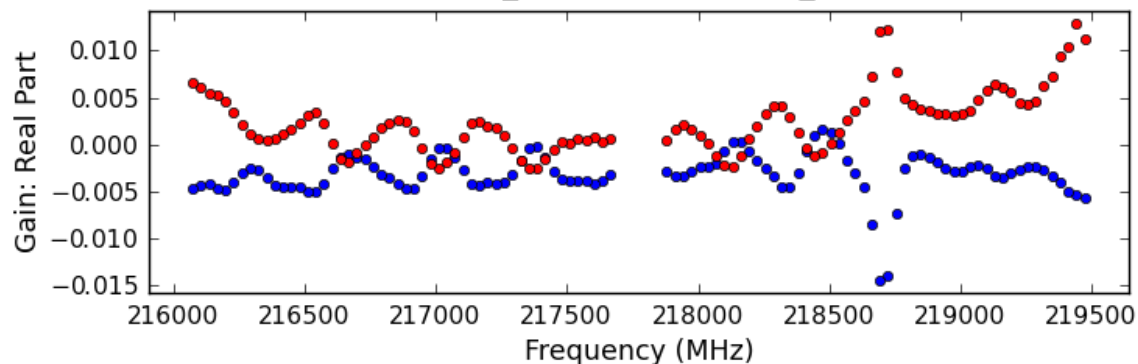
Blue: Dx

Red: Dy

Band 6 On-axis D-term

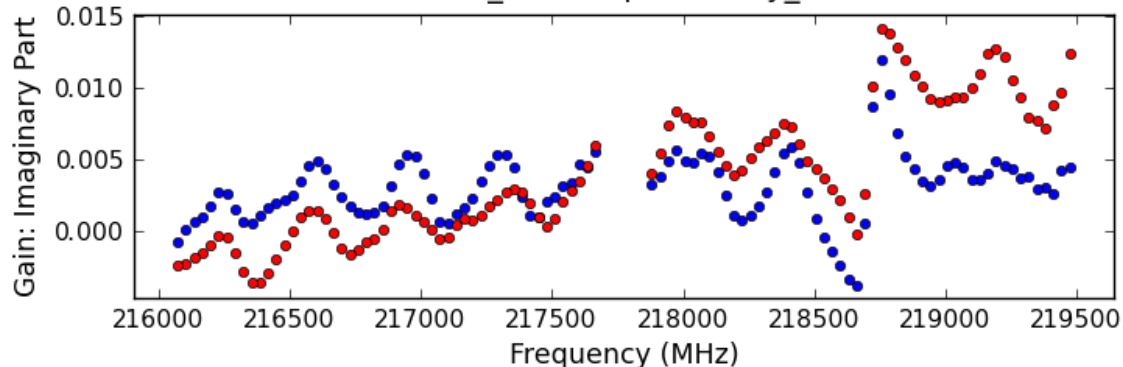
DA42

D table: 3c279_B6.ms.split.Df0sky_refant-DV23



- Typically 2-5%
- Frequency structure $\pm 0.5\%$

D table: 3c279_B6.ms.split.Df0sky_refant-DV23



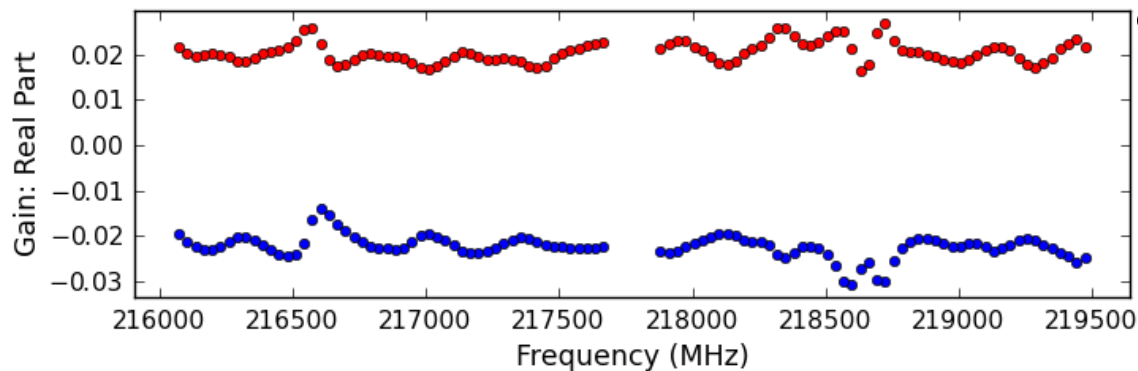
Blue: Dx

Red: Dy

Band 6 (bad antenna)

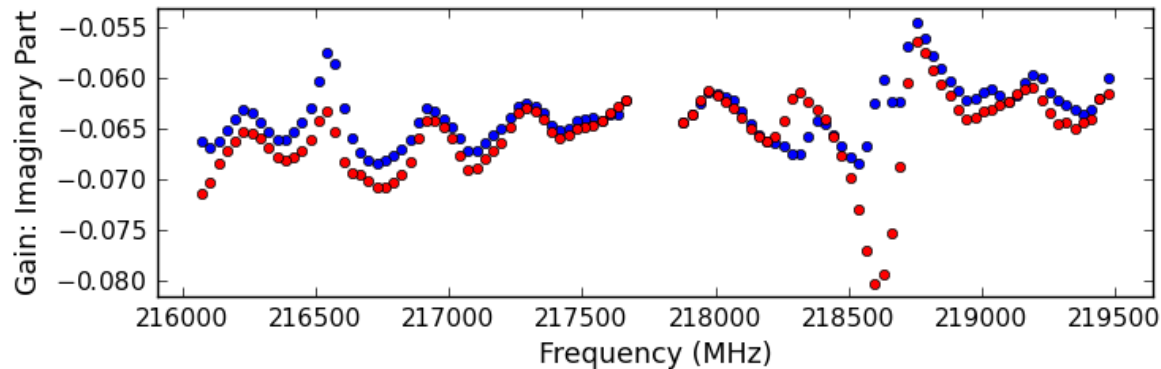
DV04

D table: 3c279_B6.ms.split.Df0sky_refant-DV23



• Few antennas > 5%

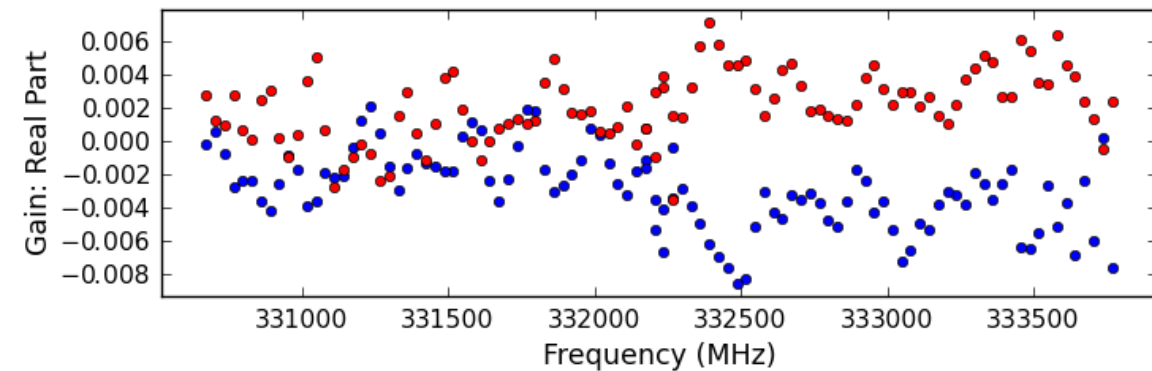
D table: 3c279_B6.ms.split.Df0sky_refant-DV23



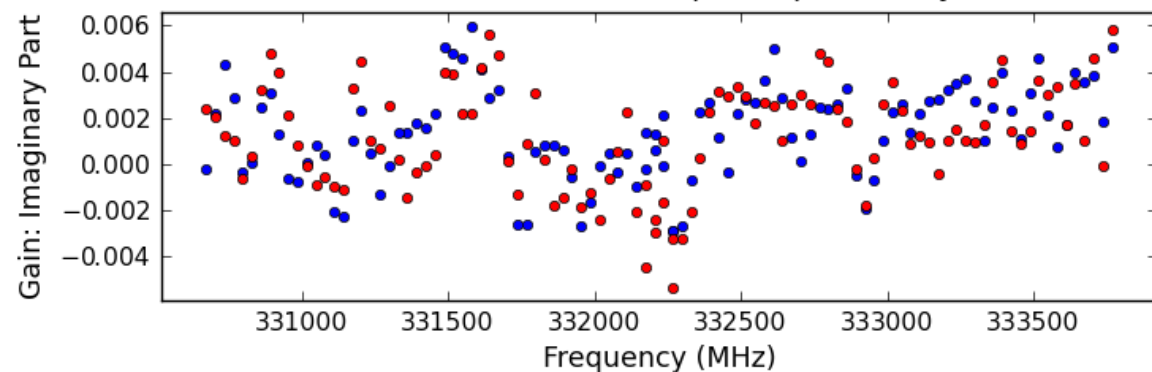
Band 7 On-axis D-term

DV04

D table: 1924B7sweep.ms.split.Df0sky



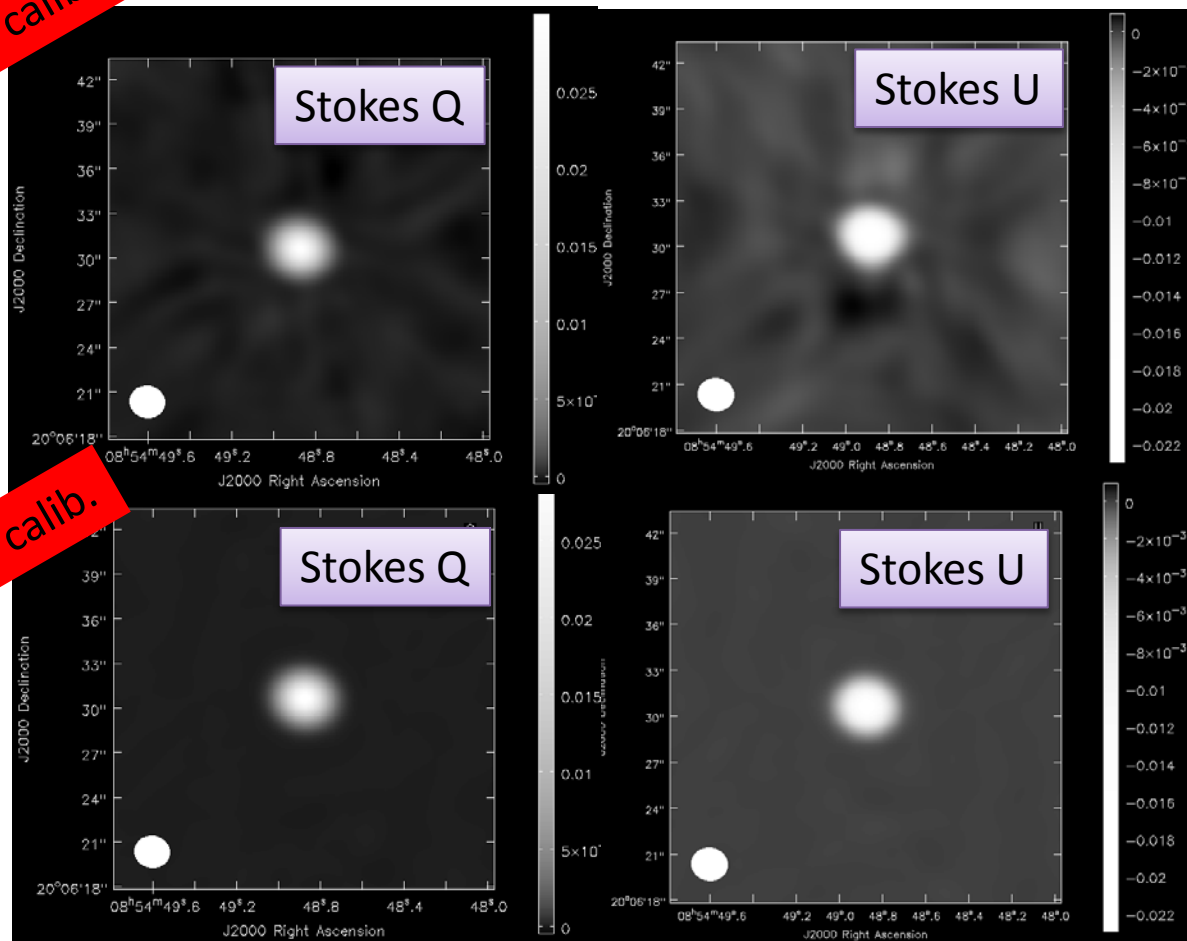
D table: 1924B7sweep.ms.split.Df0sky



- Typically $< 2\%$
- Fairly good comparing to B3/6
- Effect of wire grid?

Polarization image (Band 3)

Quasar OJ287

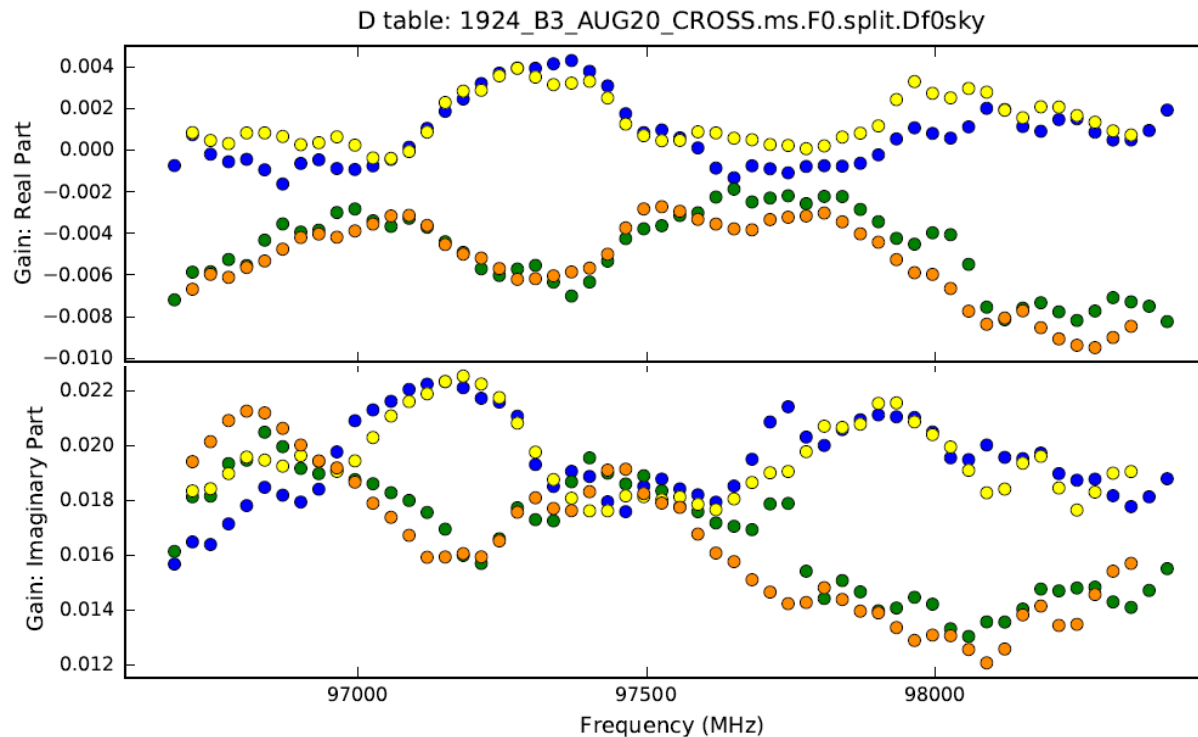


rms
=(few x 0.1%) of Stokes I

rms
=(few x 0.01%) of Stokes I

- Without D-term calibration, rms on polarization image < 1%
- Image rms improves a factor of ~ 10 by applying D-term solution
-> 0.1% polarization is detectable (meets ALMA specification)

Stability at Band 3



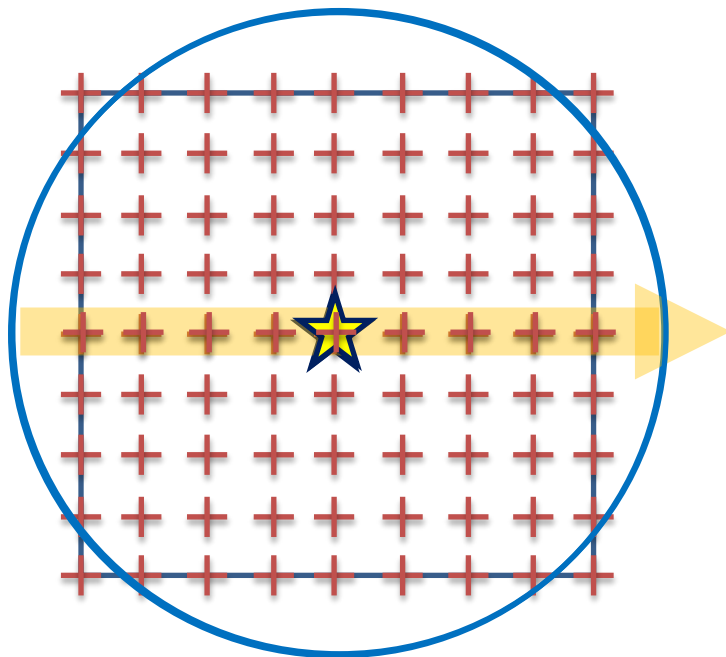
The blue (Dx) and red (Dy) represent the data on **2012/Aug/18**, the yellow (Dx) and green (Dy) represent the data on **2012/Aug/20**.

- <0.3% difference between two observations at B3
- Shorter timescale (~hrs) stability is also confirmed (CSV-2440)

Direction Dependence

DA56 (refant=DV23)

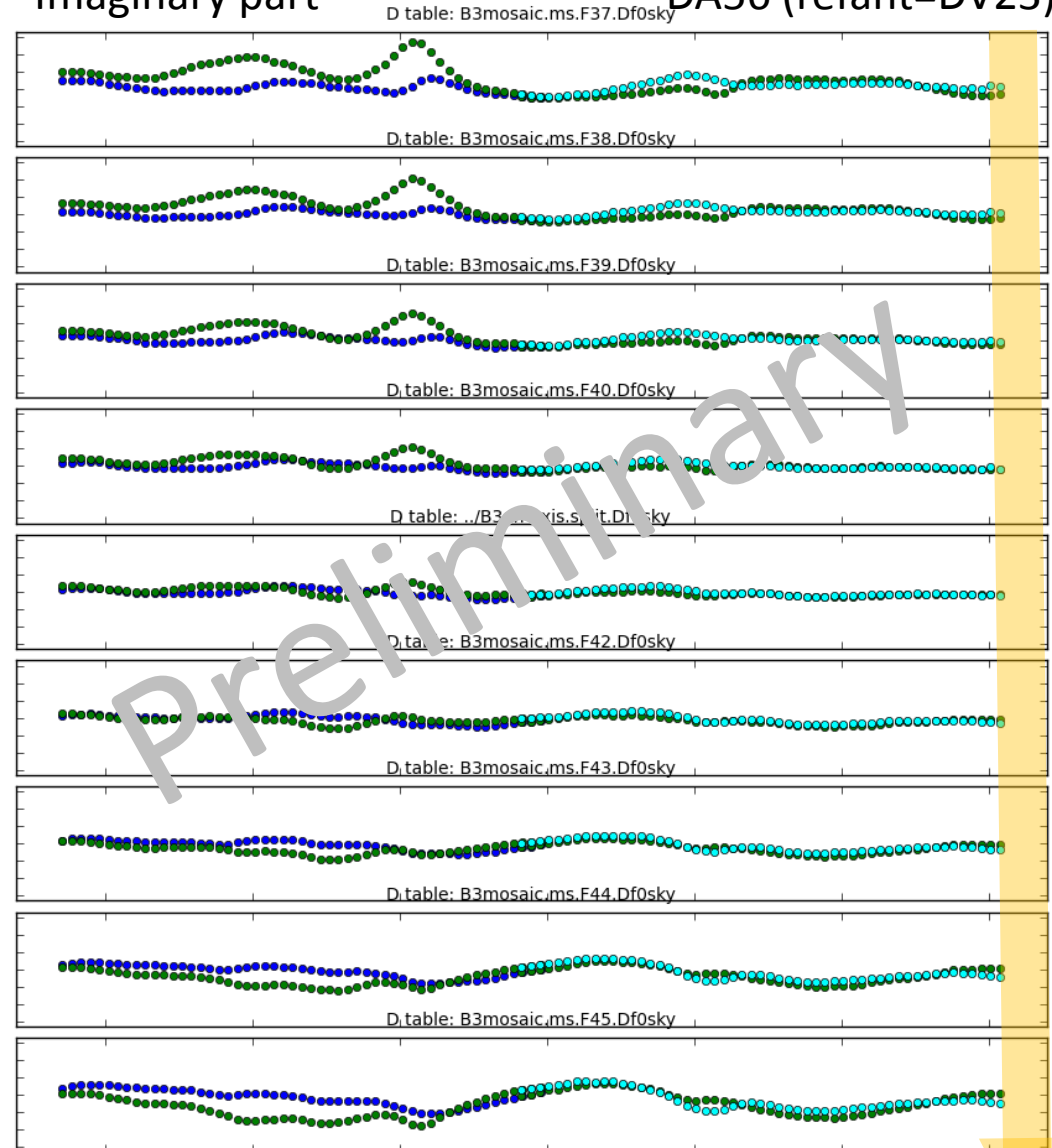
FWHM of the primary beam



Spacing: 20% of HPHW

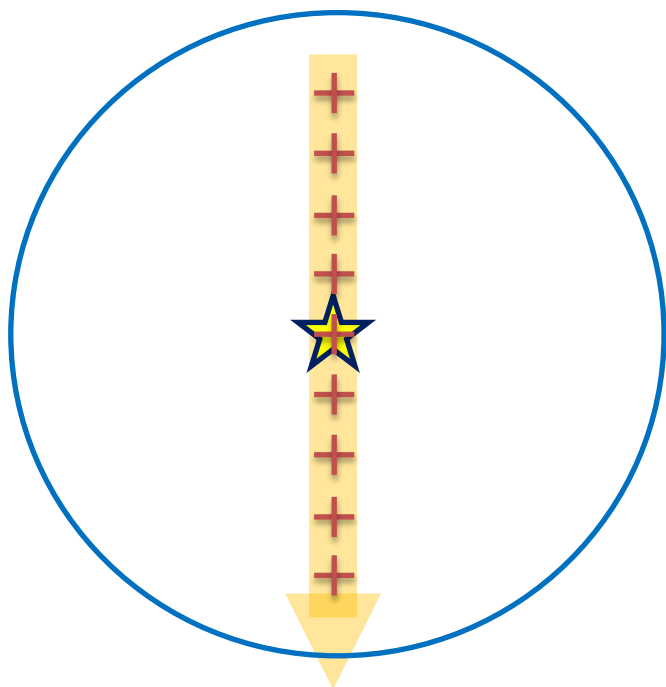
xrange [84.8GHz, 87.8GHz]
yrange [-0.06, 0.06]

Imaginary part



Direction Dependence

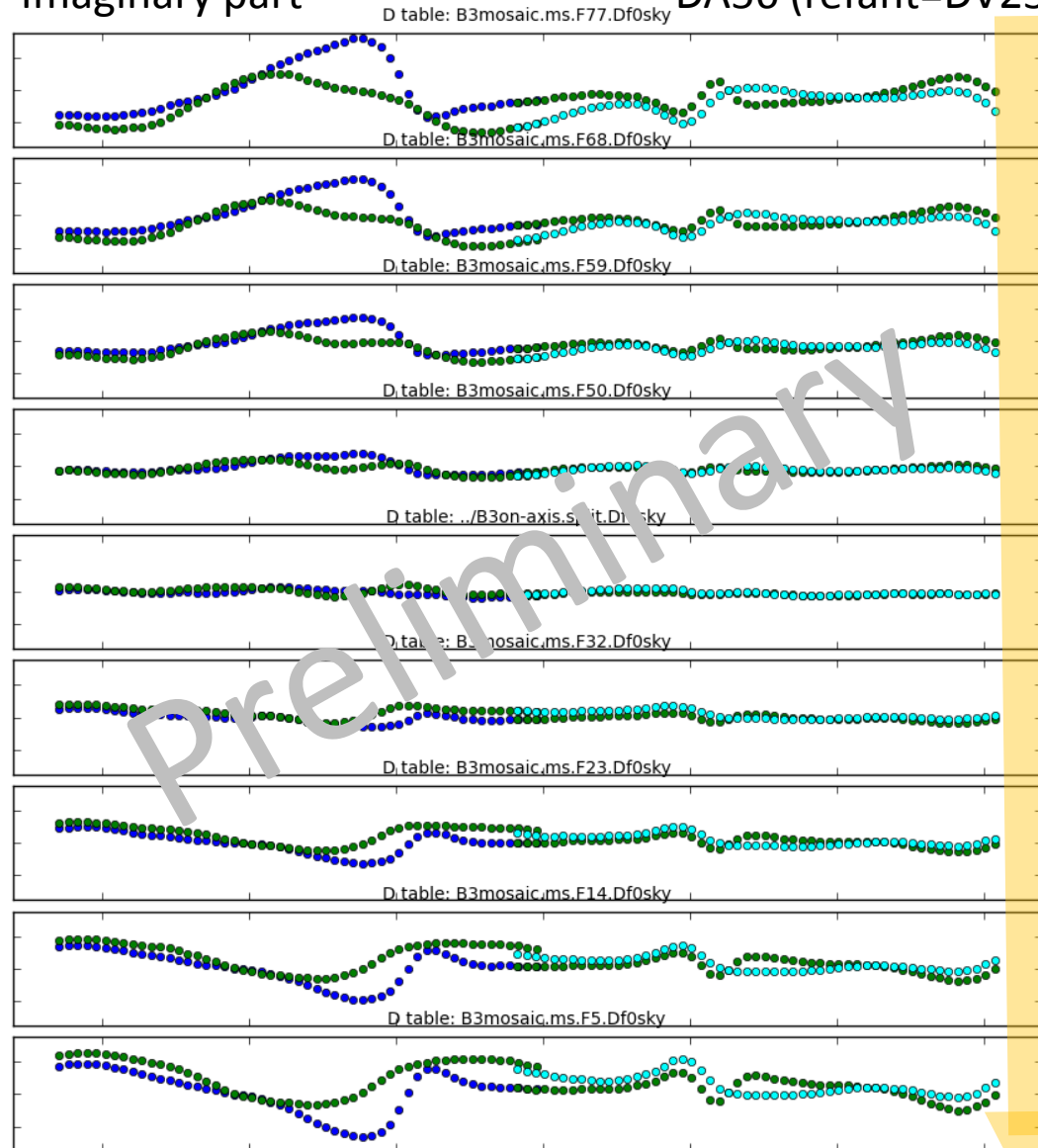
FWHM of the primary beam



xrange [84.8GHz, 87.8GHz]
yrange [-0.08, 0.08]

Imaginary part

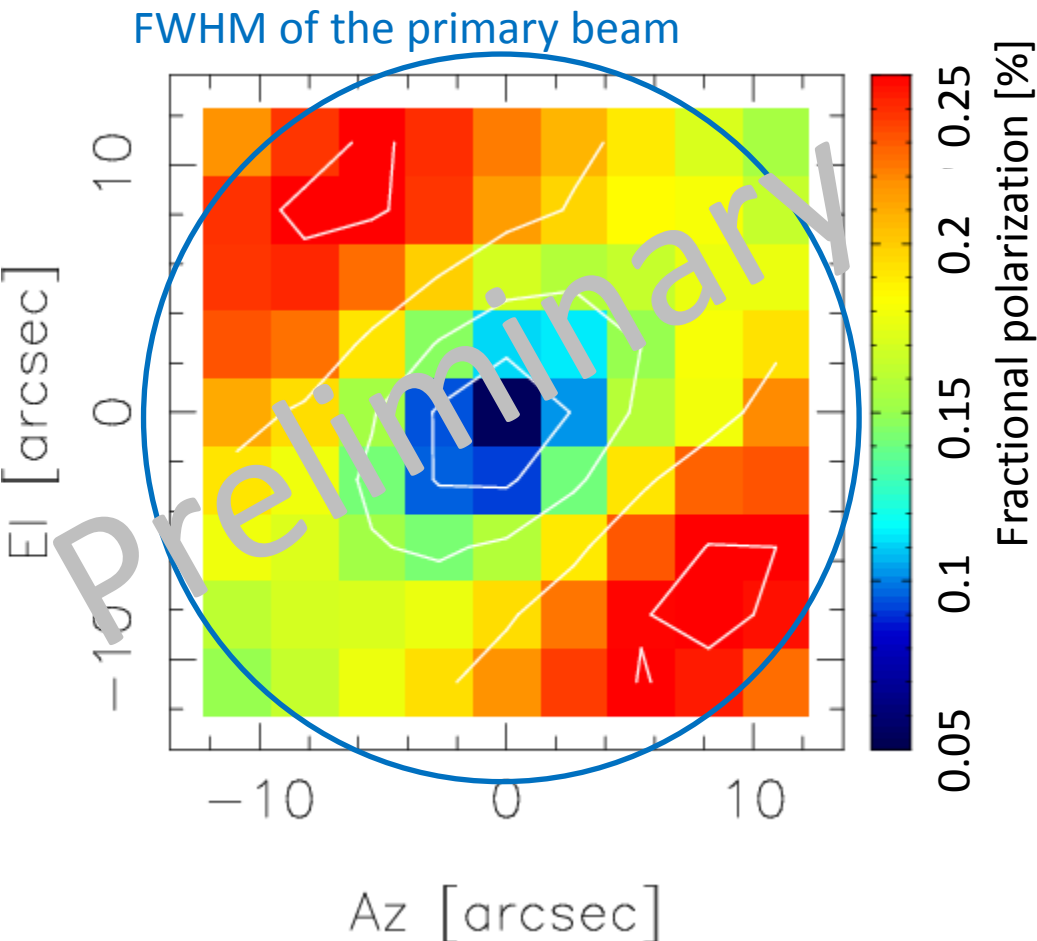
DA56 (refant=DV23)



How do we treat $D(\theta)$?

- Full calibration of off-axis D-terms needs polarization beam measurement
- Cycle 2 -> Calibration transfer from on- to off-axis (no off-axis calibration)
 - Polarization imaging is limited to the angular range where $(D_{\text{off}} - D_{\text{on}})$ is small enough

Polarization sensitivity vs. offset



- rms on polarization image as a function of offset from the on-axis
- Angular size $< \text{FWHM}/3$
 - 1% accuracy is feasible (with N of baseline $> \sim 25$)
 - 0.5% accuracy might be achievable

Band 6 (Analysis by K. Nakanishi)

Summary

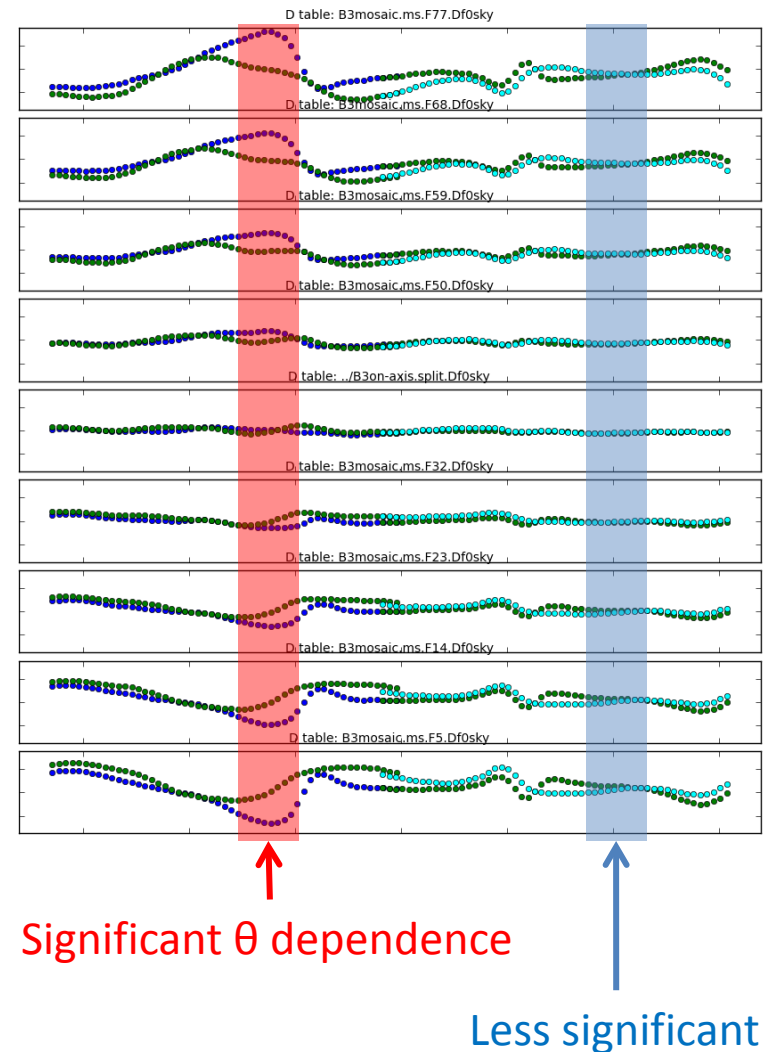
- D-term $< 5\%$ at B3/6/7 with the exception of few antennas
- Good stability
- 0.1% polarization level is detectable for the point source
- Less than 1% polarization level is achievable in the area up to FWHM/3

Preliminary Cycle 2 Capability

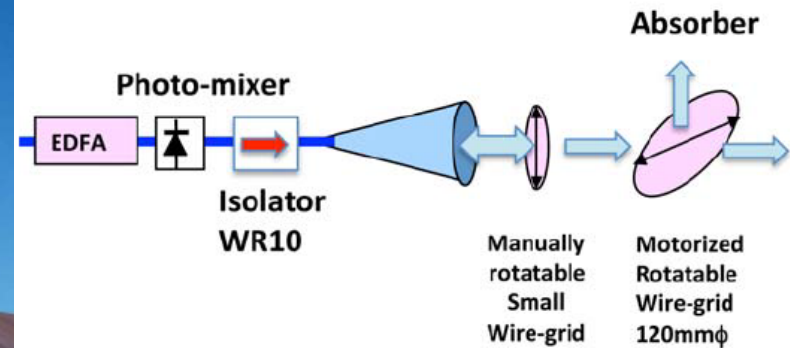
- Fixed frequency in band 3/6/7, TDM mode
- Continuum only (no spectral line observation)
- Linear polarization only (no circular polarization)
- Small angular size ($\theta_{\text{LAS}} < \text{FWHM}/3$), no mosaic
- No ACA, No TA
- Calibration strategy is still controversial
 - D-terms are measured in each execution or JAO provides D-term table?

Towards future cycles: spectral line polarimetry

- Spectral line polarimetry
 - Need bright calibrator to determine D on per-channel basis
 - Not always found near the target
 - Provides calibration table to users
 - $\Delta D(\theta)$ is frequency dependent
 - Acceptable angle for the calibration transfer from on- to off-axis might be severer



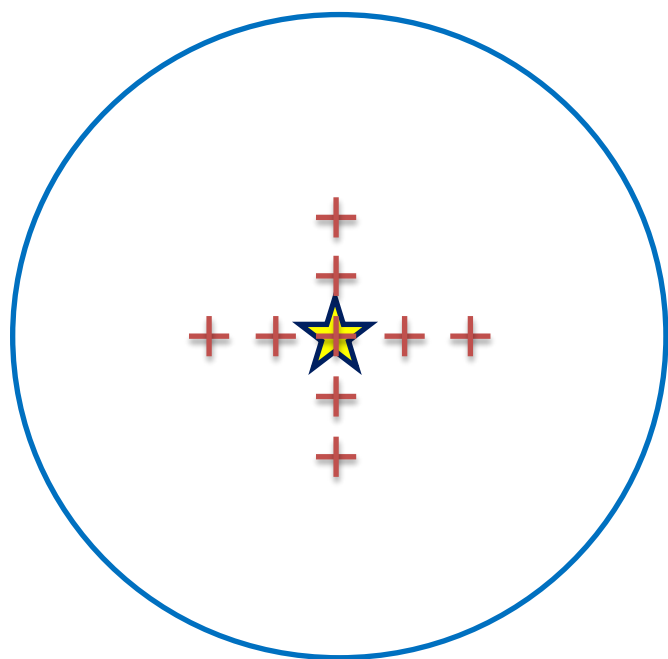
Towards future cycles: polarization beam measurement



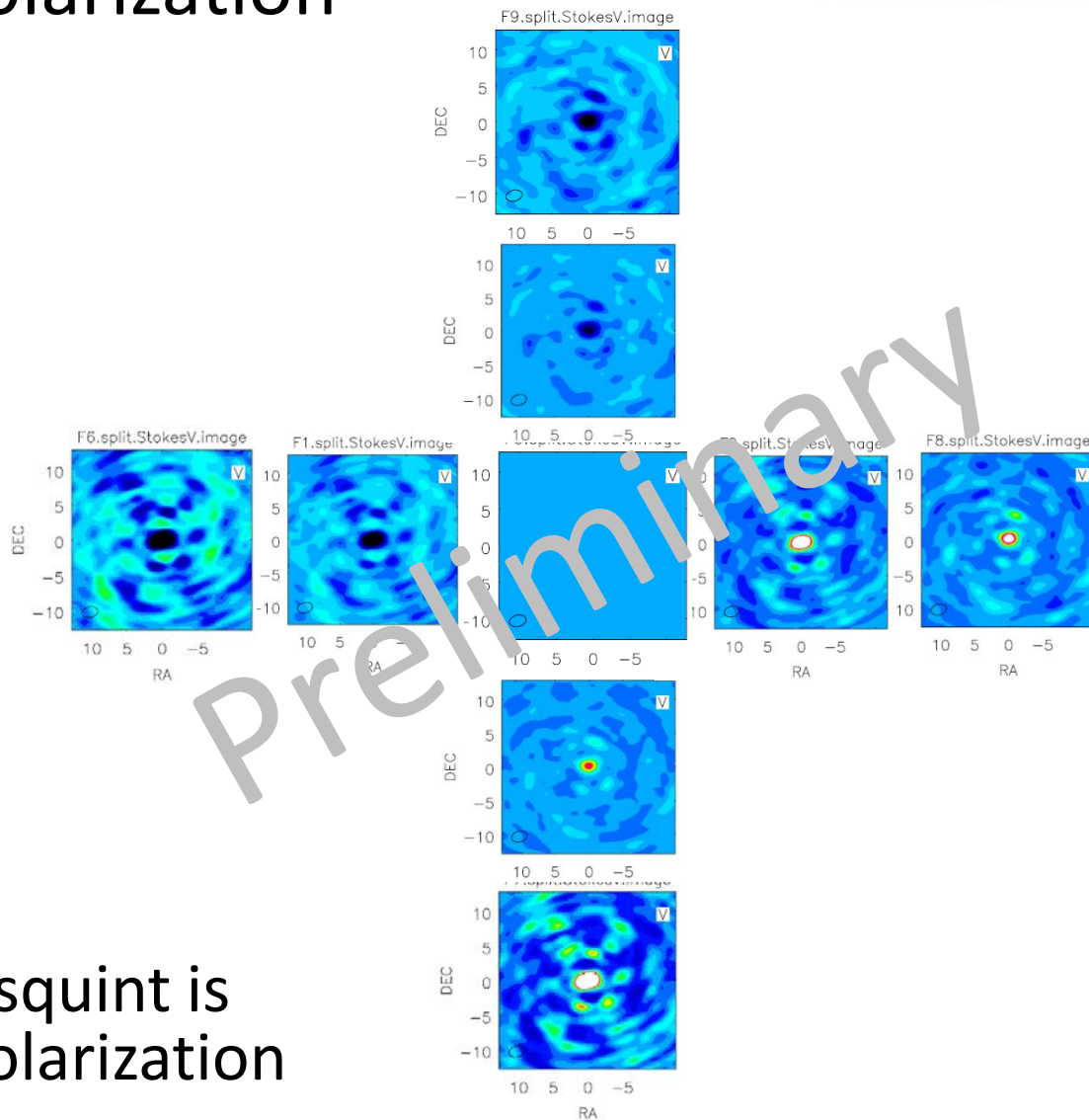
- Artificial noise source at high site (H. Kiuchi, R. Hills)
 - linear polarization signal
 - Rotatable $-45\text{deg} < \text{PA} < 45\text{deg}$
- Useful for the polarization beam measurement
- For the moment only at band 3

Towards future cycles: circular polarization

FWHM of the primary beam



- Correction of beam-squint is critical for circular polarization imaging





appendix



More detailed specification

- ON-axis instrumental polarization:
 - a) D-terms $< 10\%$ before calibration,
 - b) D-terms $< 1\%$ after calibration
 - c) this applies over 30 degrees of antenna motion in azimuth or elevation and with a calibration interval of 4 hours.
- OFF-axis instrumental polarization:
 - a) D-terms $< 10\%$ before calibration but after the ON-AXIS cross polarization has been subtracted. This applies out to the -6dB contour of the primary beam;
 - b) D-terms < -34 dB after calibration and after ON-AXIS cross-polarization has been removed;
 - c) this applies over a range of antenna elevation of 5 to 80 degrees and with a calibration interval of 20 days.