

# Polarization

## SYS#224, 225

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# Verification items

- On-axis (#224)
  - Instrumental polarization (D-term)  $< 10\%$
  - Residual after calibration  $< 1\%$ 
    - >  $0.1\%$  error on a polarization image
  - These apply over  $30$  deg in azimuth or elevation and with a calibration interval 4 hours
- Off-axis (#225)
  - D-term within the  $-6\text{dB}$  primary beam  $< 10\%$  after the subtraction of on-axis D-term
  - Residual after calibration and after on-axis D-term has been removed  $< 2\%$  -> **This statement should be revisited**
  - These apply over a range of antenna elevation of  $5$  to  $80$  degrees and with a calibration interval of 20 days

# What's D-terms?

$$\hat{V}_X = V_X + D_X V_Y$$

$$\hat{V}_Y = V_Y + D_Y V_X$$

The D terms: fraction of the input signal voltage in one polarization that leaks into the output of the other polarization.

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

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

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

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

- Mostly originates in antenna and frontend
- Typically a few % at on-axis field

# On-axis requirements

## ALMA Scientific Specifications and Requirements

Polarized flux error ( $\sigma_p$ ) < 0.1%

- There are two D-terms for each of  $\sim 50$  antennas. (in total 100 independent D-terms)
  - If the residual error after D-term calibration per antenna is  $\sim 1\%$ , the polarized flux error on a image will be 0.1% ( $=1\%/\text{sqrt}(100)$ ).
- Assuming 10% calibration accuracy, the D-term shall be  $< 10\%$ .
- These applies over a typical calibration cycle (4-hrs).

# Off-axis requirements

- There is **no scientific constraint on the off-axis polarization** in **ALMA Scientific Specifications and Requirements. SysTech Requirements (by D. Slamek)** assume that the off-axis D-term requirement applies after the on-axis D-term has been removed by calibration.
  - $(D_{\text{off}} - D_{\text{on}}) < 10\%$ , and residual  $D_{\text{off}}$  after the calibration and after on-axis D-term removed  $< 2\%$
- Above statement is not very clear, but, for the moment, we test:
  - $(D_{\text{off}} - D_{\text{on}}) < 10\%$
  - the polarized flux error at off-axis is not greater than 0.1% on a polarization image after the on-axis calibration.

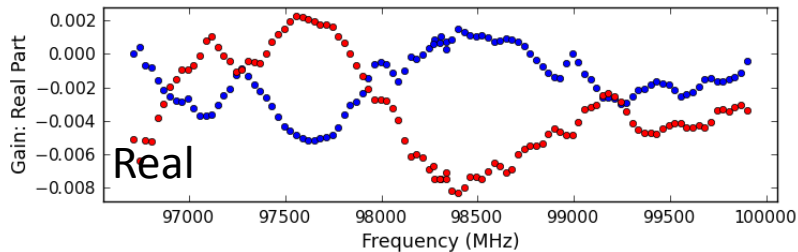
# On-axis: Procedure

- Observe a bright polarized quasar over a wide range of parallactic angle (>90deg??) and then separate source polarization and D-terms
  - The source must be polarized at a level of few %
    - See the polarization calibrator list ([CSV-2721](#))
  - Typical observation: 3min x 6 scans / frq. tuning
  - Appropriate parallactic angle range is to be tested ([CSV-2910](#))
- For the stability check, observe two polarized quasars separated by >4 hrs in hour angle.
  - Compare two D-term solutions to check the stability

# Example of D-terms

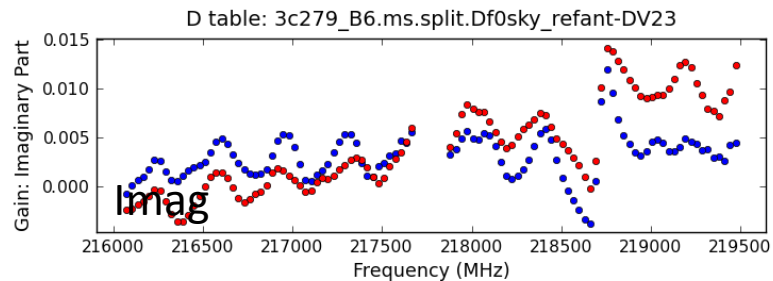
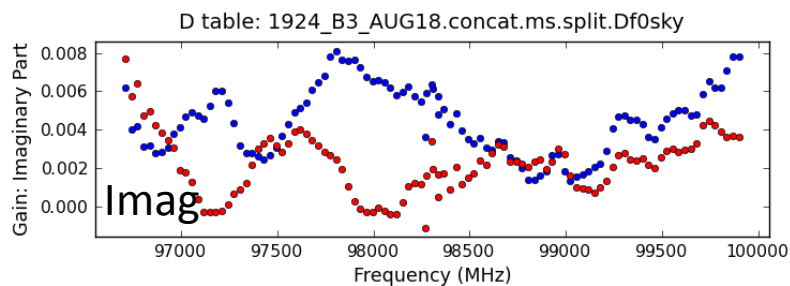
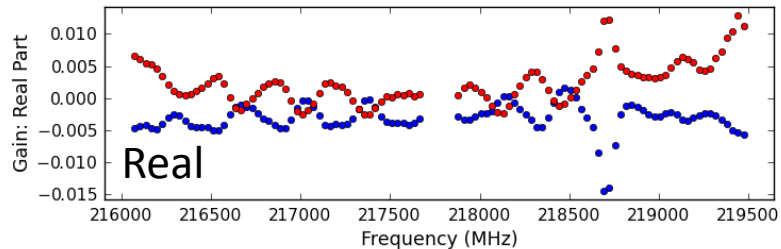
B3, DV04

D table: 1924\_B3\_AUG18.concat.ms.split.Df0sky



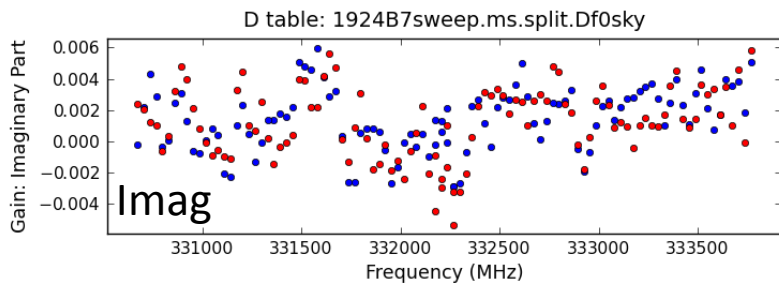
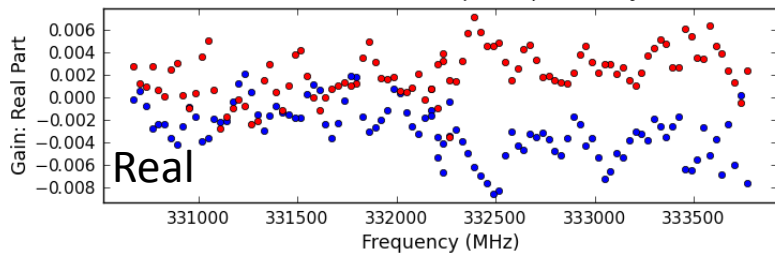
B6, DA42

D table: 3c279\_B6.ms.split.Df0sky\_refant-DV23



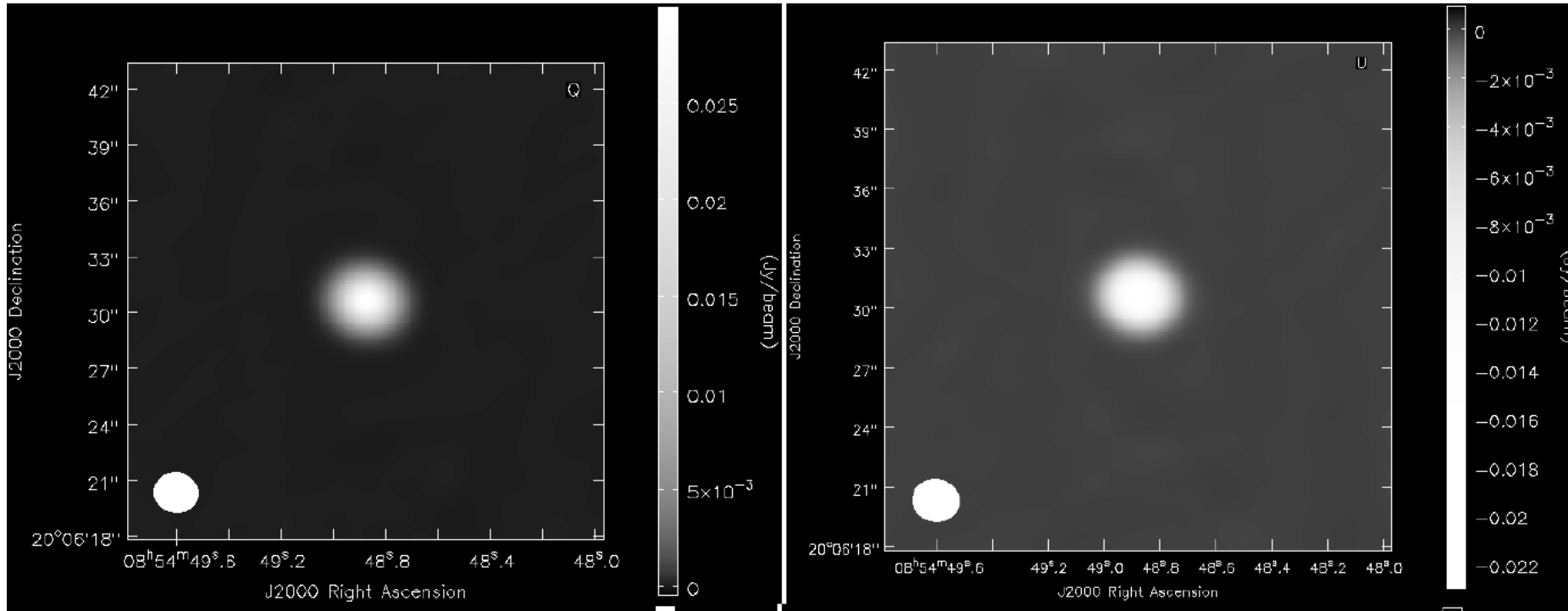
B7, DV04

D table: 1924B7sweep.ms.split.Df0sky



- Typically few %
  - Meets the requirement

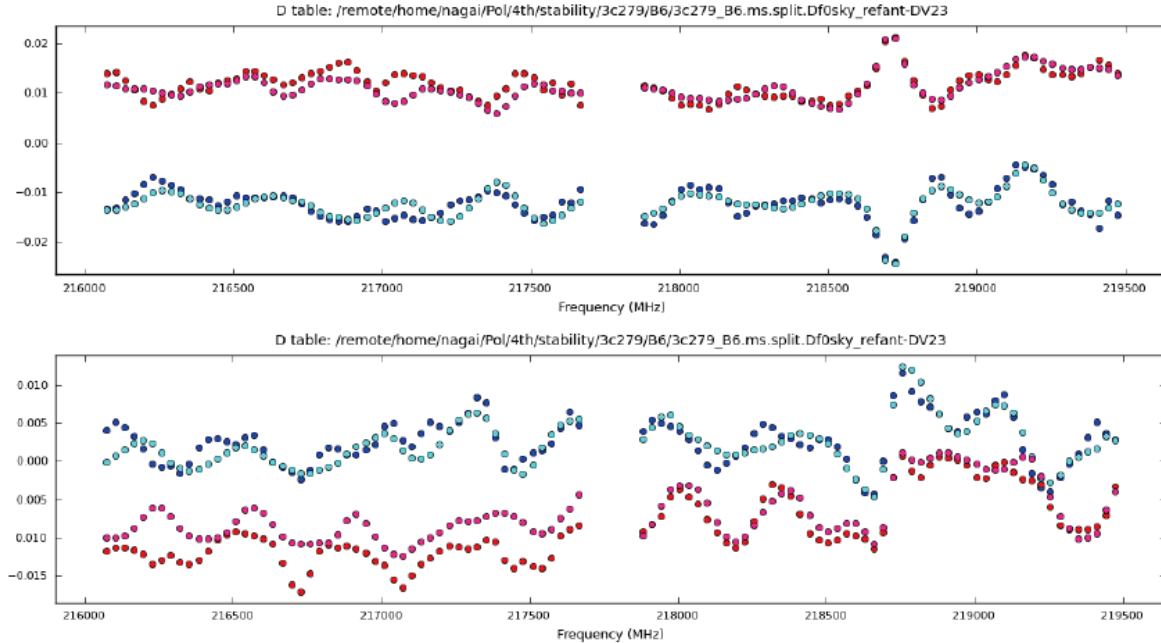
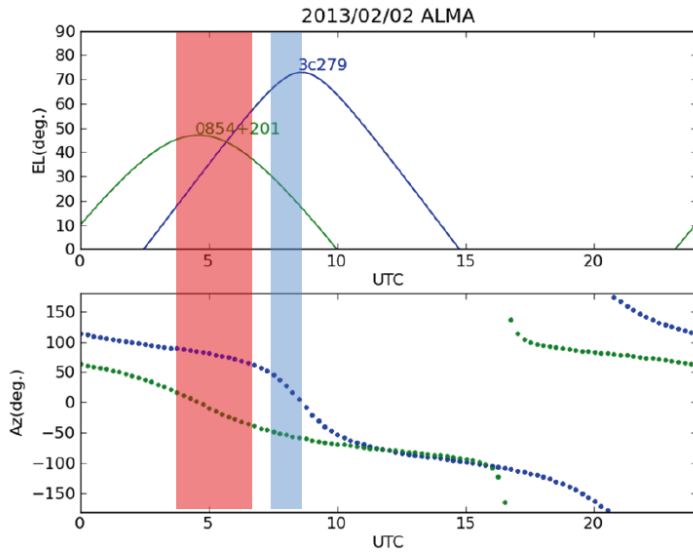
# Example of polarization image



- Stokes Q (left) and U (right) map after the D-term calibration.
- The rms on the images are  $\ll 0.1\%$  of Stokes I
  - Meets the requirement



# Stability



- Blue (Dx) and red (Dy) are solutions from 0854+201, and cyan (Dx) and pink (Dy) are solutions from 3c279.
- Two solutions agree within a level of  $\sim 0.5\%$ .
  - Meets the requirement

# On-axis Status

	B3		B6		B7	
	Observation	Analysis	Observation	Analysis	Observation	Analysis
D-term level	Done	Done	Done	Done	Done	Done
Error on pol. Image	Done	Done	Done	Done	Done	Done
Stability	Done	Done	Done	Done	Done	Not done

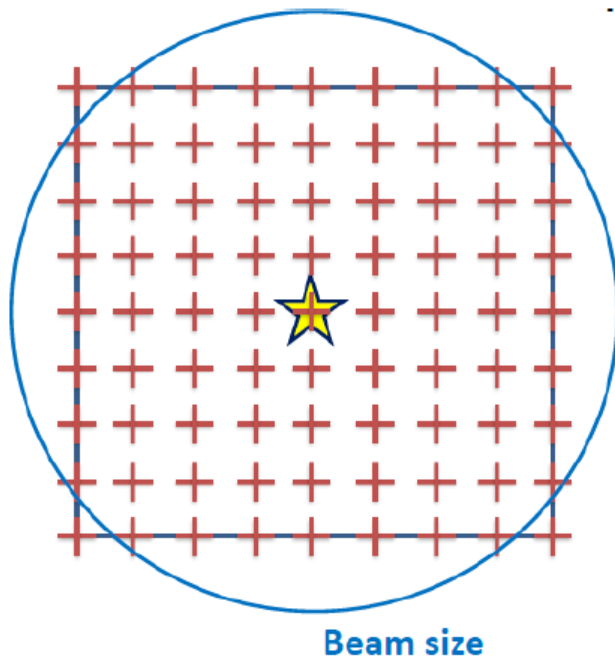
- All observations were done in **TDM mode** at **two frequency tunings** with **12-m array**.

- Future works

- FDM mode
- more frequency tunings
- Band 4,8,9
- 7m array

# Off-axis: Procedure

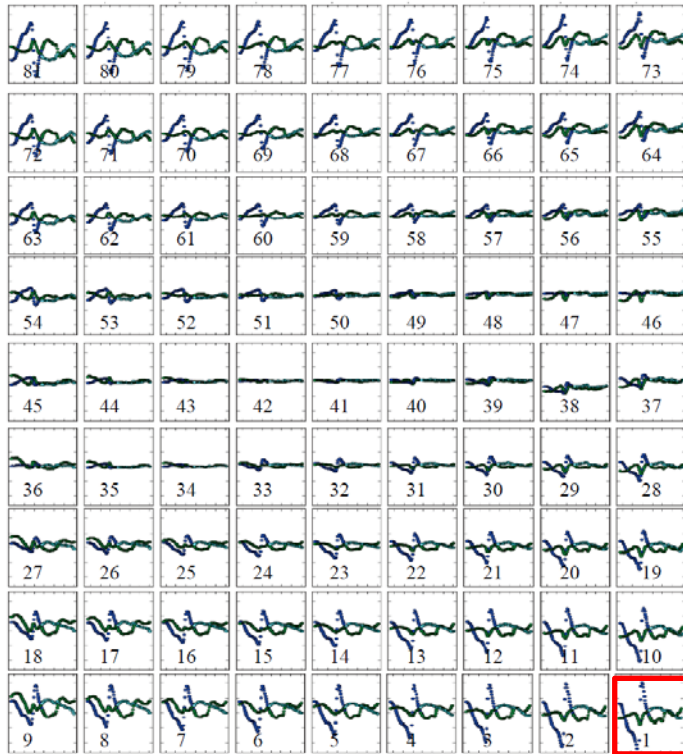
- Mosaicing to cover the -6dB contour
  - So far we have tested within -3dB
- 9 x 9 mosaic at several parallactic angles



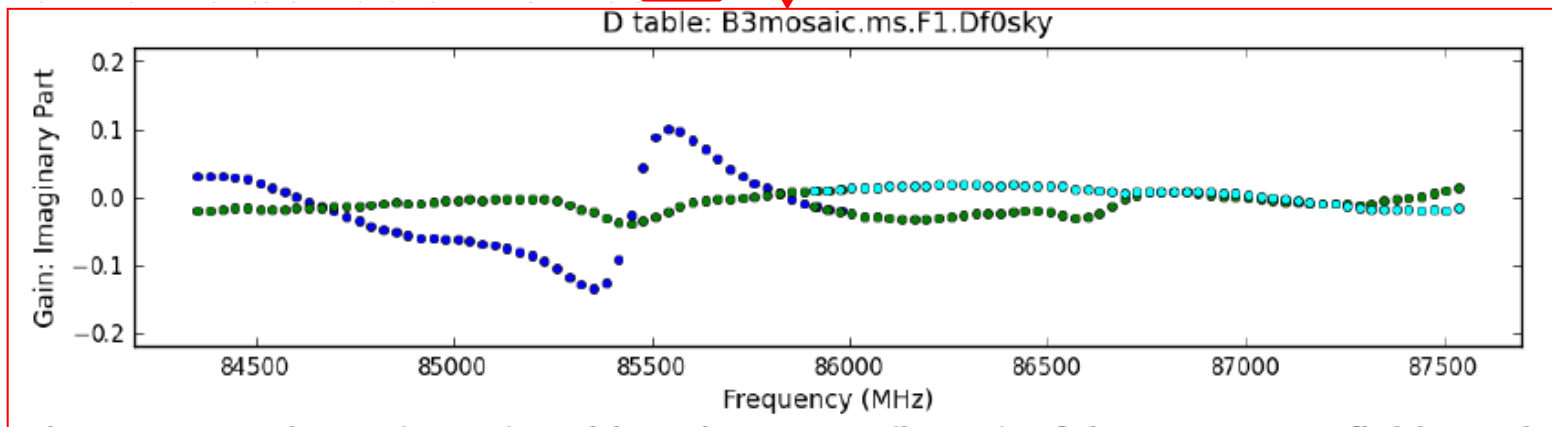
+ Pointing position

81	80	79	78	77	76	75	74	73
72	71	70	69	68	67	66	65	64
63	62	61	60	59	58	57	56	55
54	53	52	51	50	49	48	47	46
45	44	43	42	41	40	39	38	37
36	35	34	33	32	31	30	29	28
27	26	25	24	23	22	21	20	19
18	17	16	15	14	13	12	11	10
9	8	7	6	5	4	3	2	1

# Example of off-axis D-terms



- D-term level is as large as 15% at some frequency in bands 3 and 6.
  - $D_{\text{off}} - D_{\text{on}} > 10\%$ : **does not meet the requirement**
- Band-7 D-term level is good.
  - $\sim 5\%$  at the -3dB contour

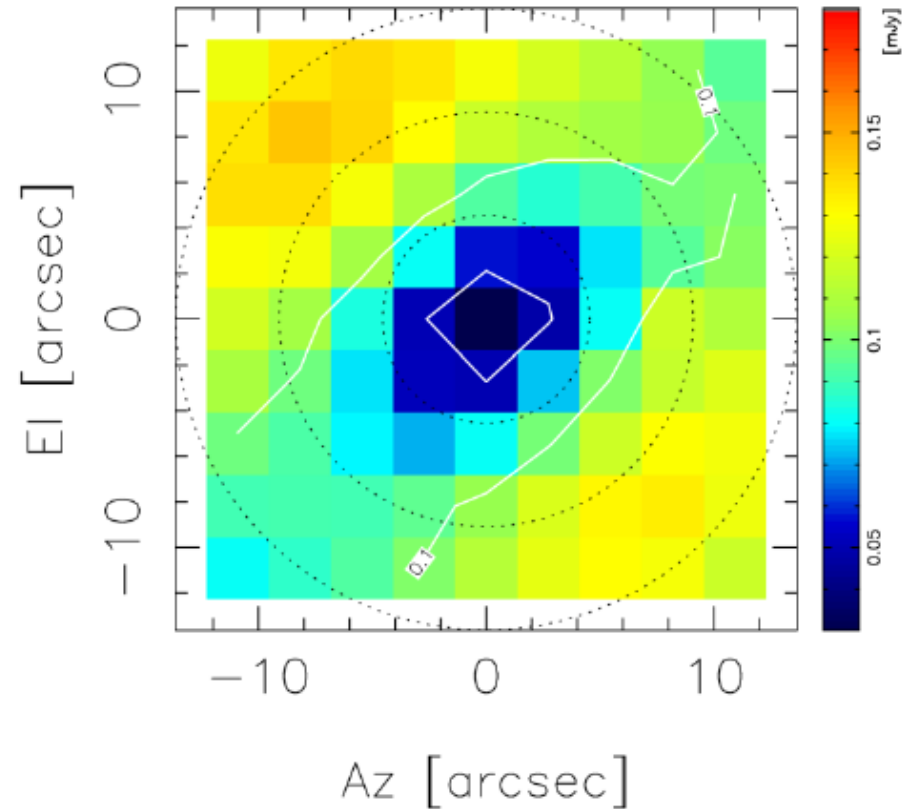
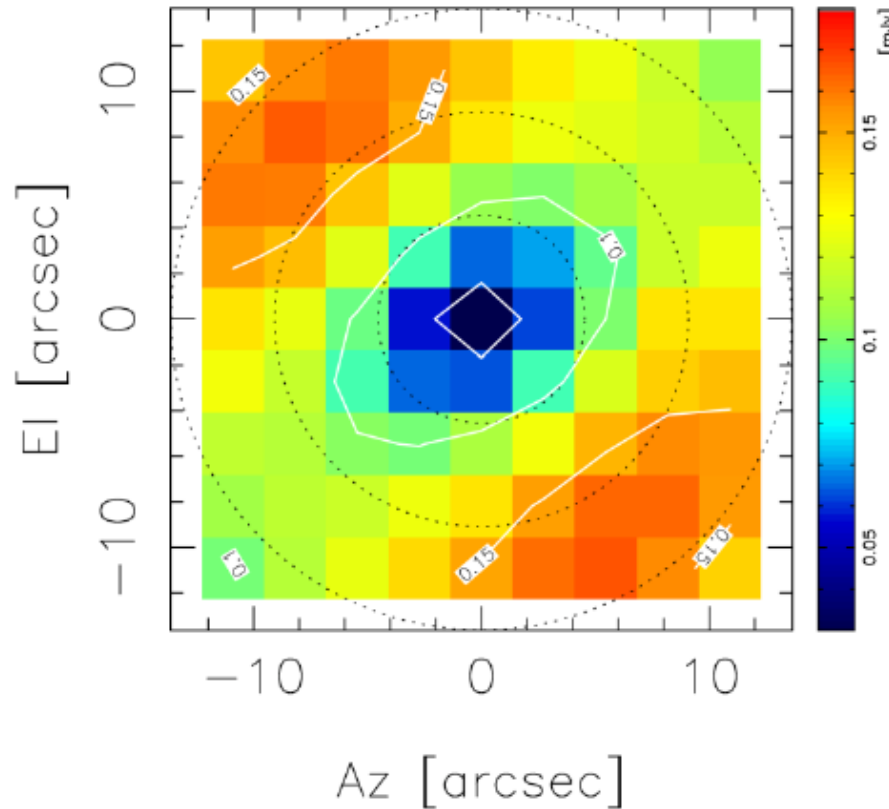


# Error on Polarization Image

Band 6

rms (Q)

rms (U)



- $< 0.1\%$  of Stokes I within  $-3\text{dB}$  contour
  - Meets the requirement

# Status

	B3		B6		B7	
	Observation	Analysis	Observation	Analysis	Observation	Analysis
D-term level	Partially done	Partially done	Partially done	Partially done	Partially done	Partially done
Error on pol. Image	Partially done	Partially done	Partially done	Partially done	Partially done	Partially done
Stability	Not done	Not done	Not done	Not done	Not done	Not done

- All observations were done **within -3dB contour** in **TDM mode** at **one frequency tunings** with 12m array
- Future works
  - **Out to -6dB contour**
  - **FDM mode**
  - **more frequency tunings**
  - **Band 4,8,9**
  - **Stability**
  - **7m array**

# Hand-over?

- Basic script for data analysis is attached in the report #224, but there is still room for improvements
- I can continue to work on these polarization verification with an agreement by EA Project Manager (S. Iguchi).
- I believe K. Nakanishi will also continue to work in CSV side.