JPSS J1 VIIRS Polarization Sensitivity Analysis and Impact

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Outline

JPSS J1 VIIRS Polarization Sensitivity

- Sensor requirements
- Testing overview
- Analysis methodology
- Results
- Impact on science
- Future work

Sensor Requirements

Polarization Sensitivity Requirements

V_PRD-12624 The VIIRS Sensor linear polarization sensitivity of the VIS and NIR bands shall be less than or equal to the values indicated in table for scan angles less than 45 degrees of Nadir.

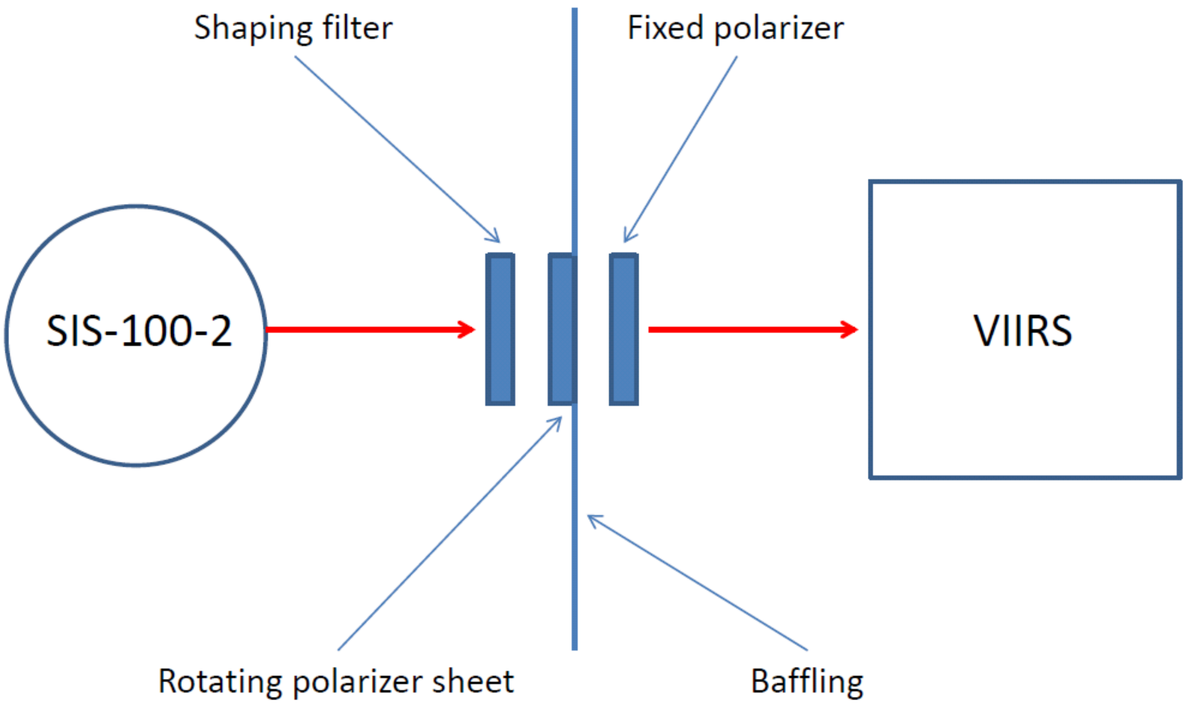
Band	Sensitivity [%]
I2, M1, M7	3
I1, M2, M3, M4, M5, M6	2.5

V_PRD-12667 The VIIRS Sensor linear polarization sensitivity shall be measured within a characterization uncertainty of 0.5% (one sigma) for scan angles less than 55.84 degrees off Nadir.

Test Setup

JPSS J1 VIIRS Polarization Sensitivity

- Sensor level test – FP-11 (component level testing also performed)
  - Source – SIS-100-2
  - Two sheet polarizers used – BVO777 and BVONIR
  - Shaping filter used for some bands (Sonoma and Hoya)
  - Various baffling also installed to minimize stray light
- VisNIR bands and DNB tested



Methodology

1) Check stray light data – both dark and "lollipop" test configurations
   Determine if there is any contamination
2) Determine efficiency of polarizer from cross-polarizer data
   Use zeroth and second order terms in Fourier series
3) Analyze polarization sensitivity data to determine the polarization amplitude and phase
   Use zeroth through fourth order terms in Fourier series

$$dn(\alpha) = \frac{1}{2}c_0\left[1 + \sum_{n=1}^{4} a_n \cos(2\alpha - \delta_n)\right]$$

where the polarization factor (amplitude) and phase are defined as

$$a_2 = \frac{\sqrt{c_2^2 + d_2^2}}{\frac{1}{2}c_0\sqrt{a_2^{eff}}} \qquad \delta_n = \tan^{-1}\left(\frac{d_2}{c_2}\right)$$

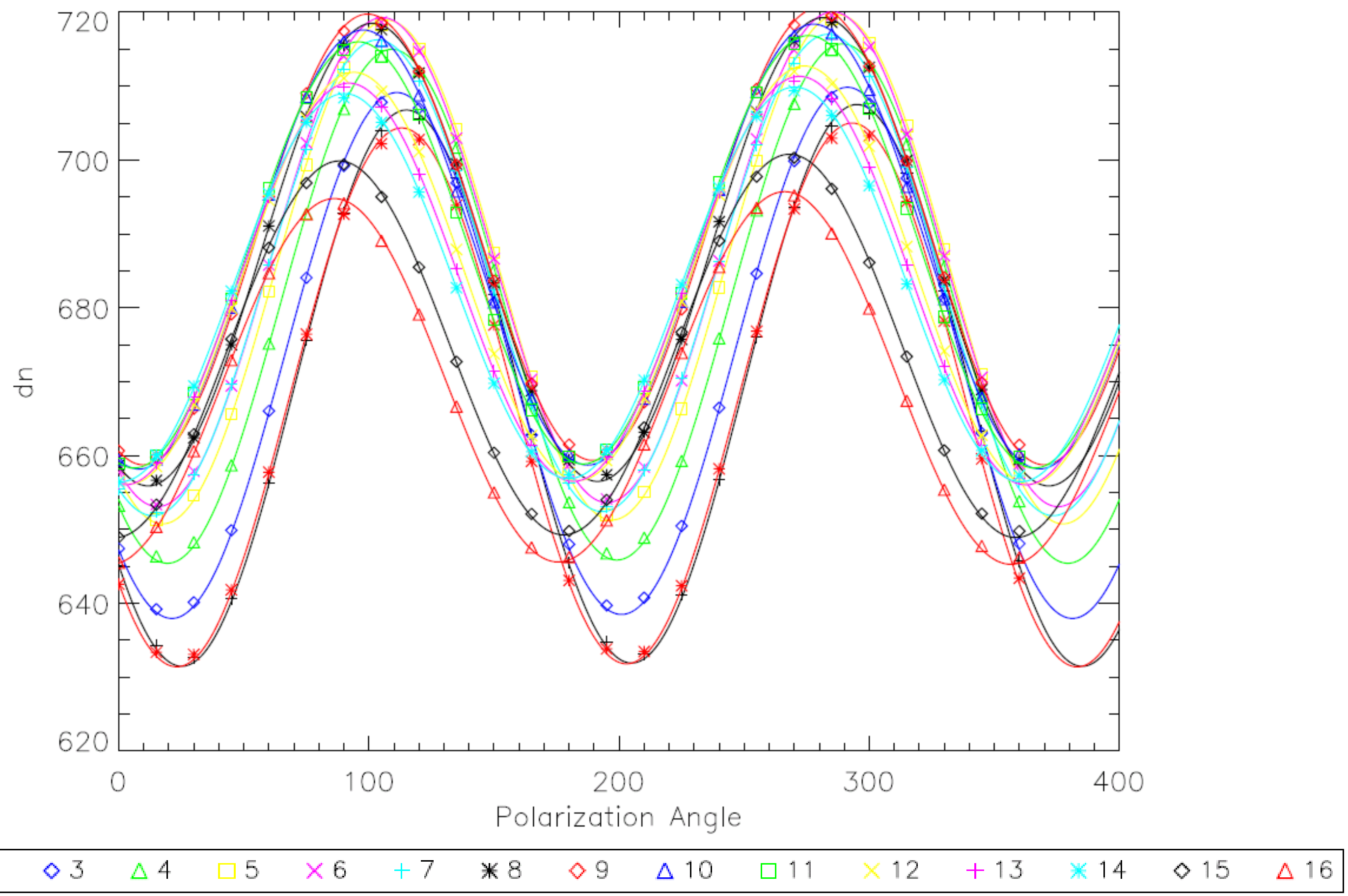
including polarizer efficiency correction factor (a_2^{eff})

Fourier Analysis

Fourier Analysis – M1 HAM A using the BVONIR polarizer with the Sonoma filter shown (-8 degrees scan angle)

Data is well reproduced by Fourier series

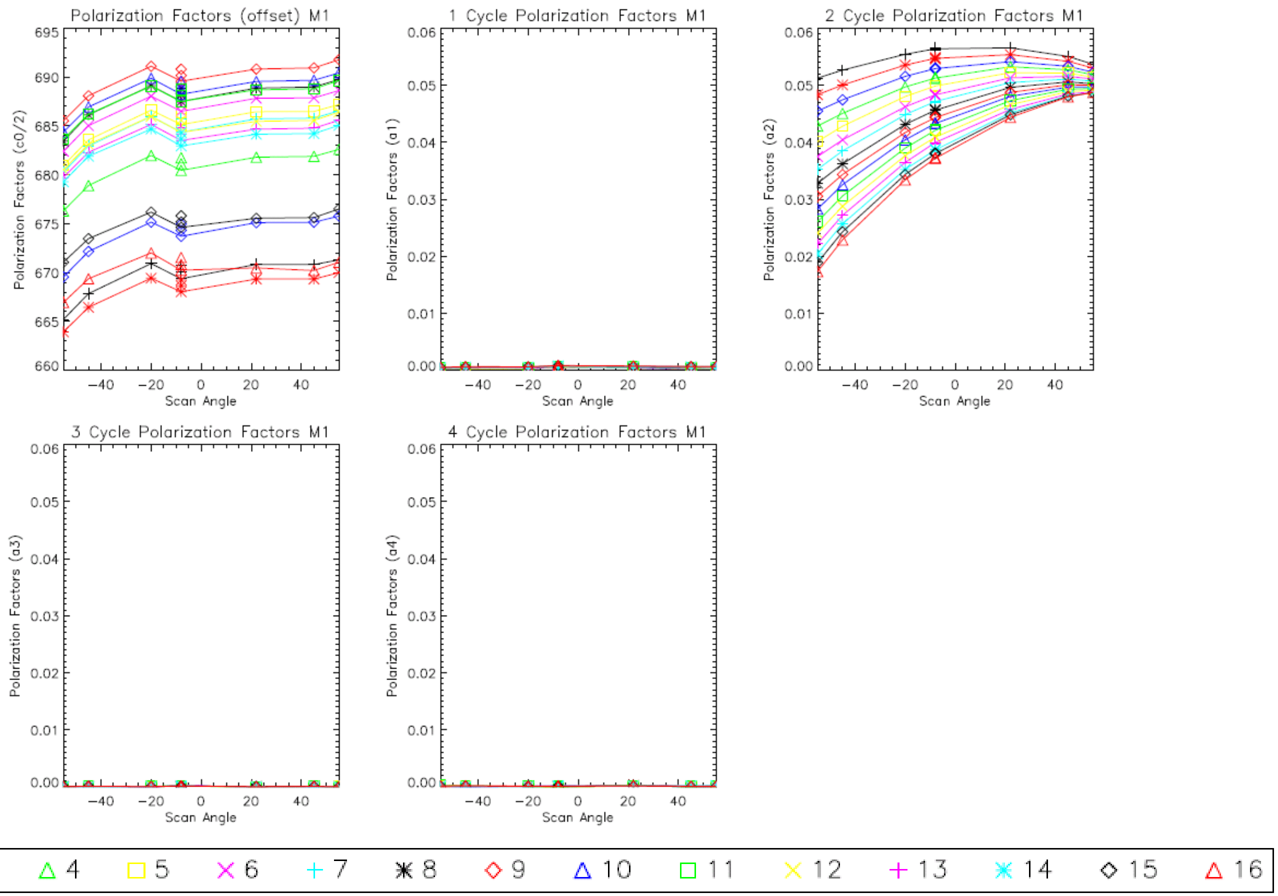
Symbols – measured data; Lines – Fourier series



Fourier Analysis

Zeroth through fourth order terms in the Fourier expansion (M1 HAM A, BVONIR polarizer with the Sonoma filter)

- 1st, 3rd, and 4th order terms are generally subdominant (results consistent for all bands)
- Large detector, scan angle, and HAM (not shown) dependence observed

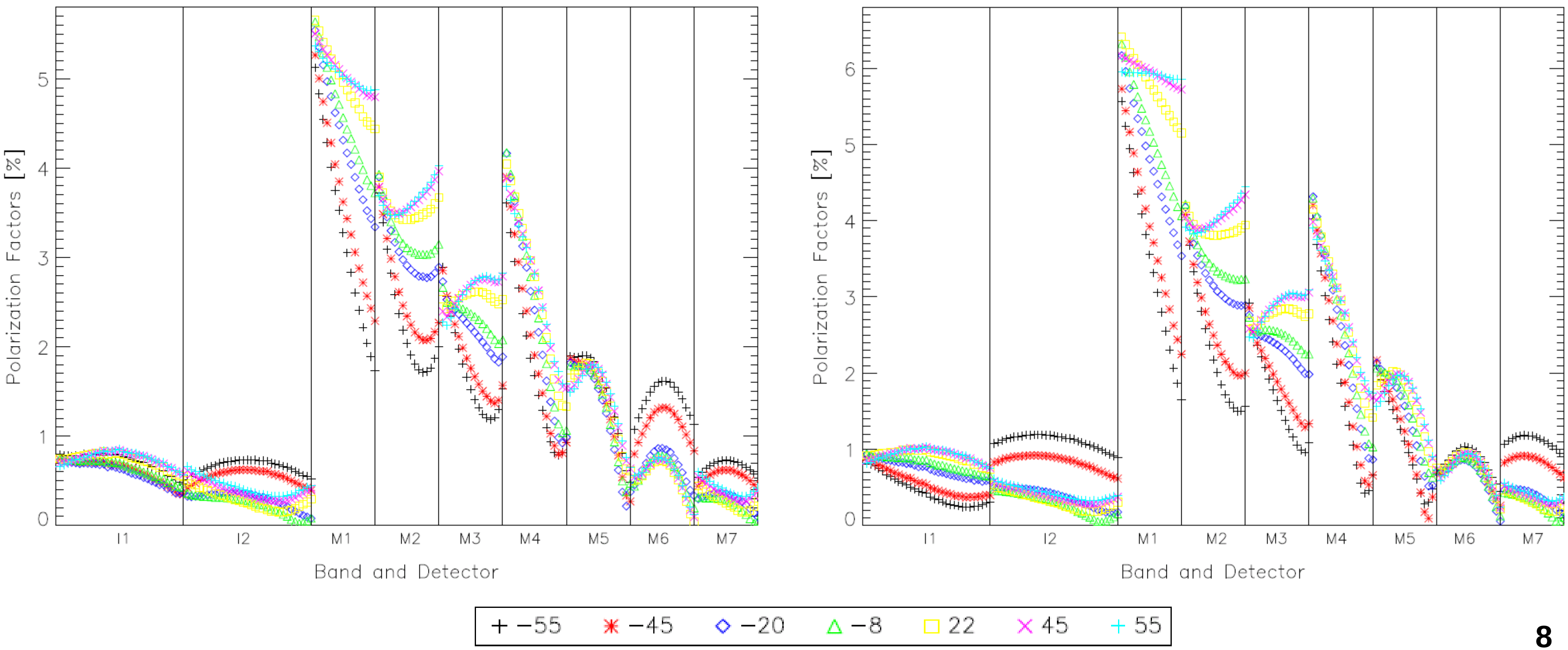


Polarization Factors

Polarization factors (BVONIR)

- BVONIR w/ Sonoma: M1-M3; BVONIR w/o Sonoma: I1-I2, M4-M7
- HAM side dependence
- Large scan angle and detector dependence

HAM A　　　　　　　　HAM B

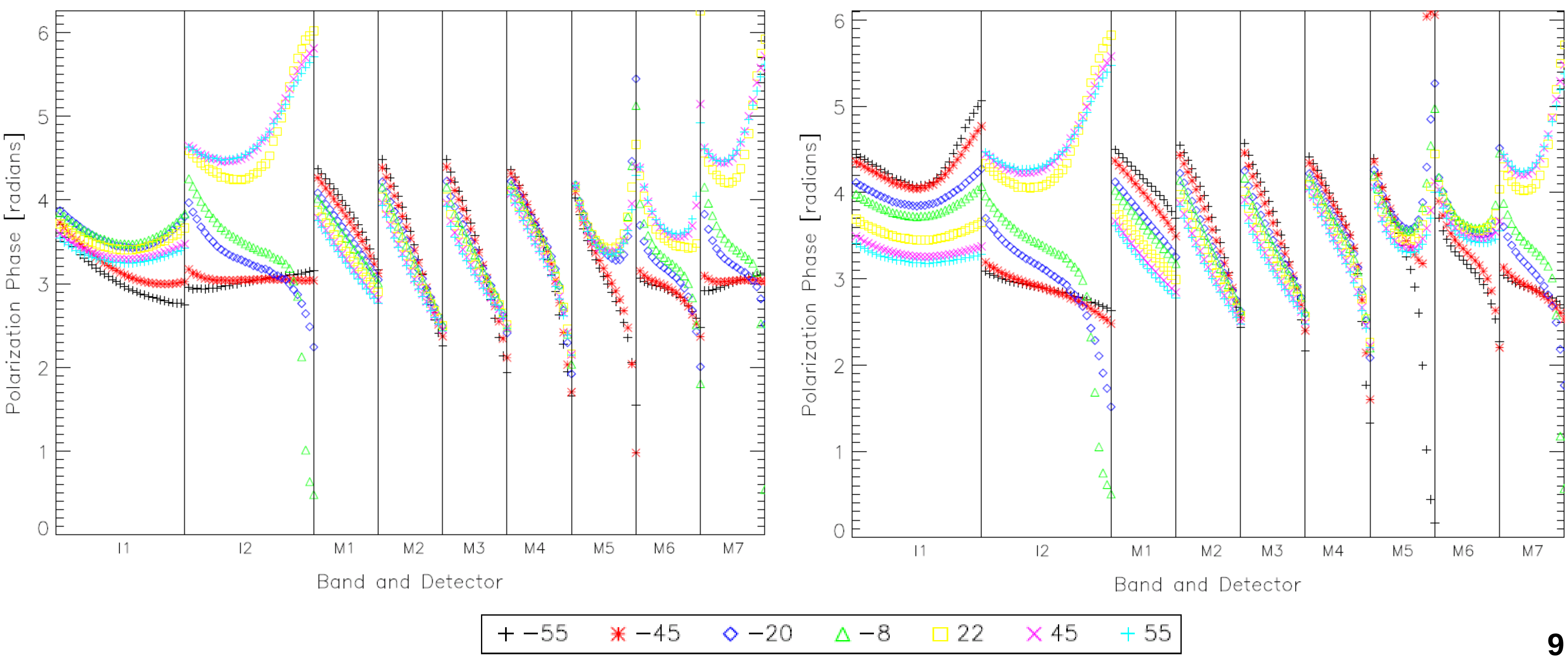


Polarization Phases

Polarization phases (BVONIR)

- BVONIR w/ Sonoma: M1-M3; BVONIR w/o Sonoma: I1-I2, M4-M7
- HAM side dependence
- Large scan angle and detector dependence

HAM A   HAM B

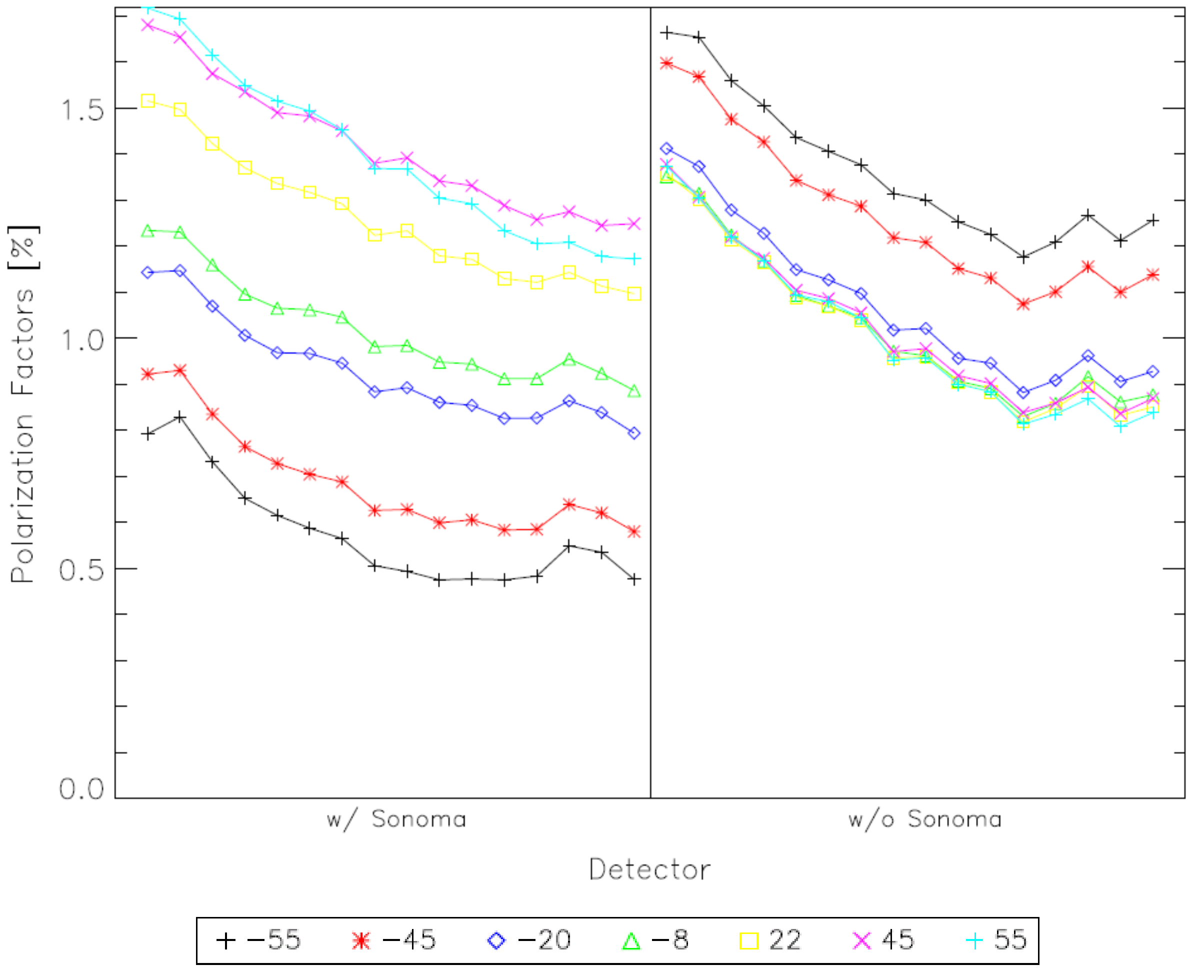


DNB Polarization Factors

DNB LGS polarization factors – BVONIR, HAM A

DNB is broadband (~500 – 900 nm)

Scan angle dependence appears consistent with VisNIR bands



Requirements Verification

Band	Sensor	Scan Angle						
		-55	-45	-22	-8	20	45	55
I1	SNPP	1.50	1.24	0.93	0.85	0.70	0.64	0.62
	JPSS J1	0.81	0.74	0.73	0.76	0.82	0.85	0.85
I2	SNPP	0.29	0.27	0.34	0.37	0.47	0.51	0.51
	JPSS J1	0.73	0.62	0.36	0.37	0.50	0.61	0.66
M1	SNPP	2.99	2.63	1.95	1.79	1.42	1.21	1.40
	JPSS J1	5.13	5.26	5.54	5.65	5.66	5.51	5.37
M2	SNPP	2.11	1.97	1.63	1.53	1.28	1.17	1.29
	JPSS J1	3.72	3.79	3.90	3.94	3.90	3.99	4.04
M3	SNPP	1.20	1.14	0.90	0.82	0.61	0.70	0.80
	JPSS J1	2.89	2.85	2.73	2.68	2.62	2.80	2.84
M4	SNPP	1.05	1.10	1.19	1.16	1.00	0.88	0.84
	JPSS J1	3.61	3.90	4.17	4.18	4.04	3.89	3.80
M5	SNPP	1.19	1.02	0.85	0.84	0.76	0.73	0.69
	JPSS J1	1.90	1.86	1.82	1.79	1.81	1.80	1.80
M6	SNPP	0.99	0.96	0.94	0.94	0.88	0.82	0.76
	JPSS J1	1.62	1.32	0.86	0.79	0.73	0.75	0.76
M7	SNPP	0.17	0.19	0.25	0.28	0.38	0.42	0.41
	JPSS J1	0.73	0.62	0.36	0.32	0.45	0.55	0.60

Requirements verification – maximum polarization factors (HAM A)

I2, M1, M7: less than 3%; I1, M2, M3, M4, M5, M6: less than 2.5%

Applies to scan angles within ±45 degrees of nadir

Requirements Verification

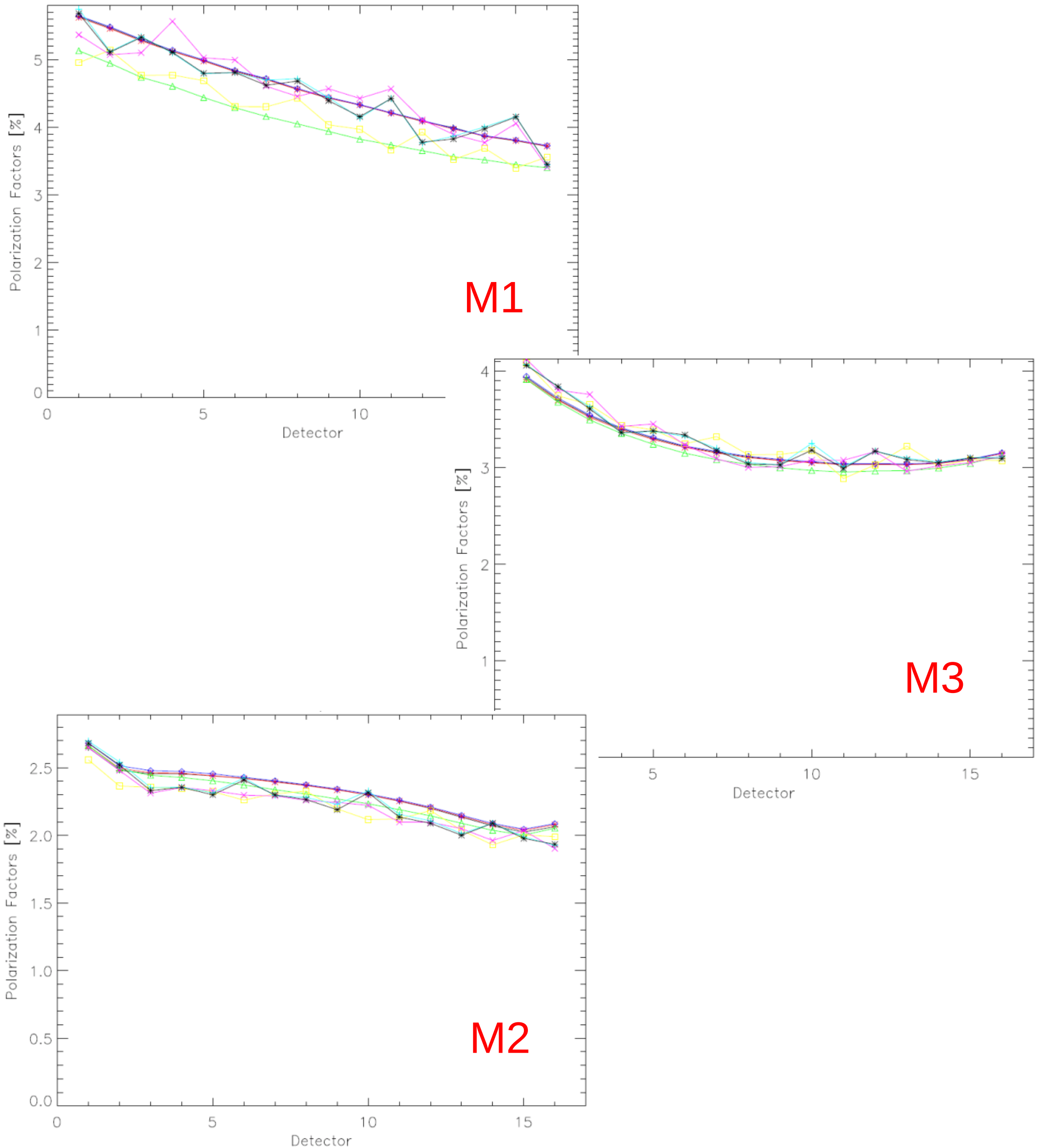
Band	Sensor	Scan Angle						
		-55	-45	-22	-8	20	45	55
I1	SNPP	0.86	0.76	0.62	0.59	0.54	0.58	0.61
	JPSS J1	0.86	0.90	0.94	0.95	1.00	1.03	1.04
I2	SNPP	0.49	0.45	0.47	0.51	0.56	0.56	0.55
	JPSS J1	1.19	0.92	0.50	0.48	0.53	0.58	0.61
M1	SNPP	3.14	2.73	2.01	1.83	1.45	1.23	1.39
	JPSS J1	5.57	5.73	6.17	6.34	6.42	6.17	5.96
M2	SNPP	2.25	2.05	1.65	1.54	1.28	1.17	1.30
	JPSS J1	4.08	4.08	4.18	4.23	4.19	4.36	4.46
M3	SNPP	1.45	1.31	0.96	0.85	0.62	0.71	0.81
	JPSS J1	2.92	2.86	2.76	2.75	2.85	3.08	3.11
M4	SNPP	1.59	1.52	1.37	1.30	1.02	0.86	0.82
	JPSS J1	4.03	4.20	4.32	4.30	4.15	3.99	3.91
M5	SNPP	0.81	0.74	0.70	0.69	0.61	0.59	0.57
	JPSS J1	2.10	2.17	2.13	2.07	2.02	1.99	1.97
M6	SNPP	1.29	1.14	0.96	0.92	0.81	0.75	0.70
	JPSS J1	1.03	0.92	0.86	0.91	0.96	0.95	0.94
M7	SNPP	0.52	0.47	0.43	0.44	0.48	0.47	0.45
	JPSS J1	1.18	0.92	0.48	0.43	0.47	0.52	0.56

Requirements verification – maximum polarization factors (HAM B)

I2, M1, M7: less than 3%; I1, M2, M3, M4, M5, M6: less than 2.5%

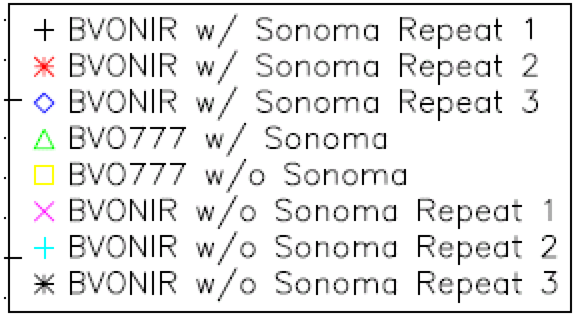
Applies to scan angles within ±45 degrees of nadir

Test Configuration Comparison



Comparing different test configurations at -8 degrees scan angle

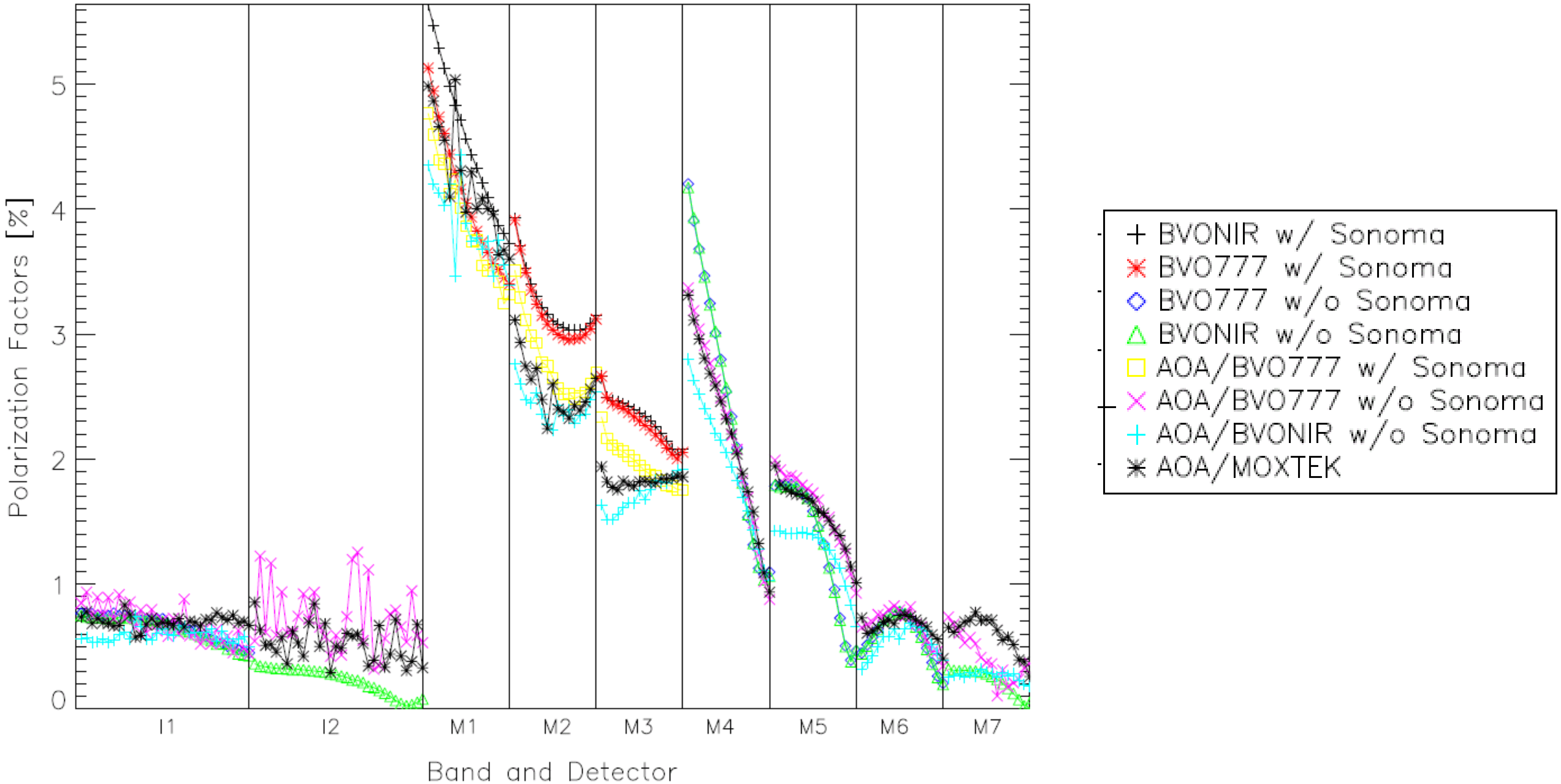
- Polarization factors
  - without the Sonoma filter less well determined for M1 – M3 (much lower source level)
- Polarization factors
  - derived using BVO777 slightly lower than BVONIR (especially for M1)



Subassembly / Sensor Comparison

Comparing tests at the subassembly and sensor levels

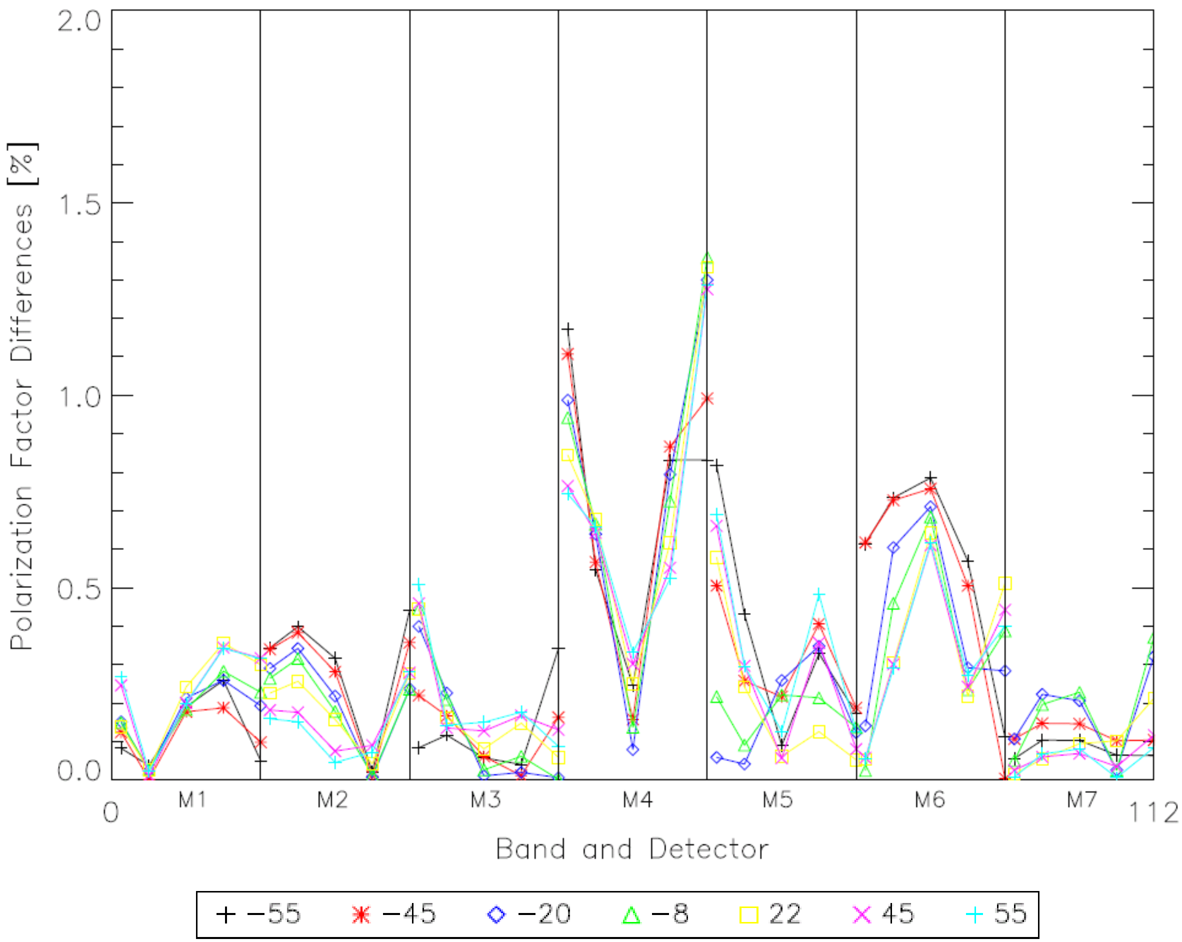
- Compared subassembly measurements to -8 degrees scan angle sensor measurements (HAM A)
- BVONIR and MOXTEK subassembly measurements were not optimized for M1-M3
- In general, results are consistent



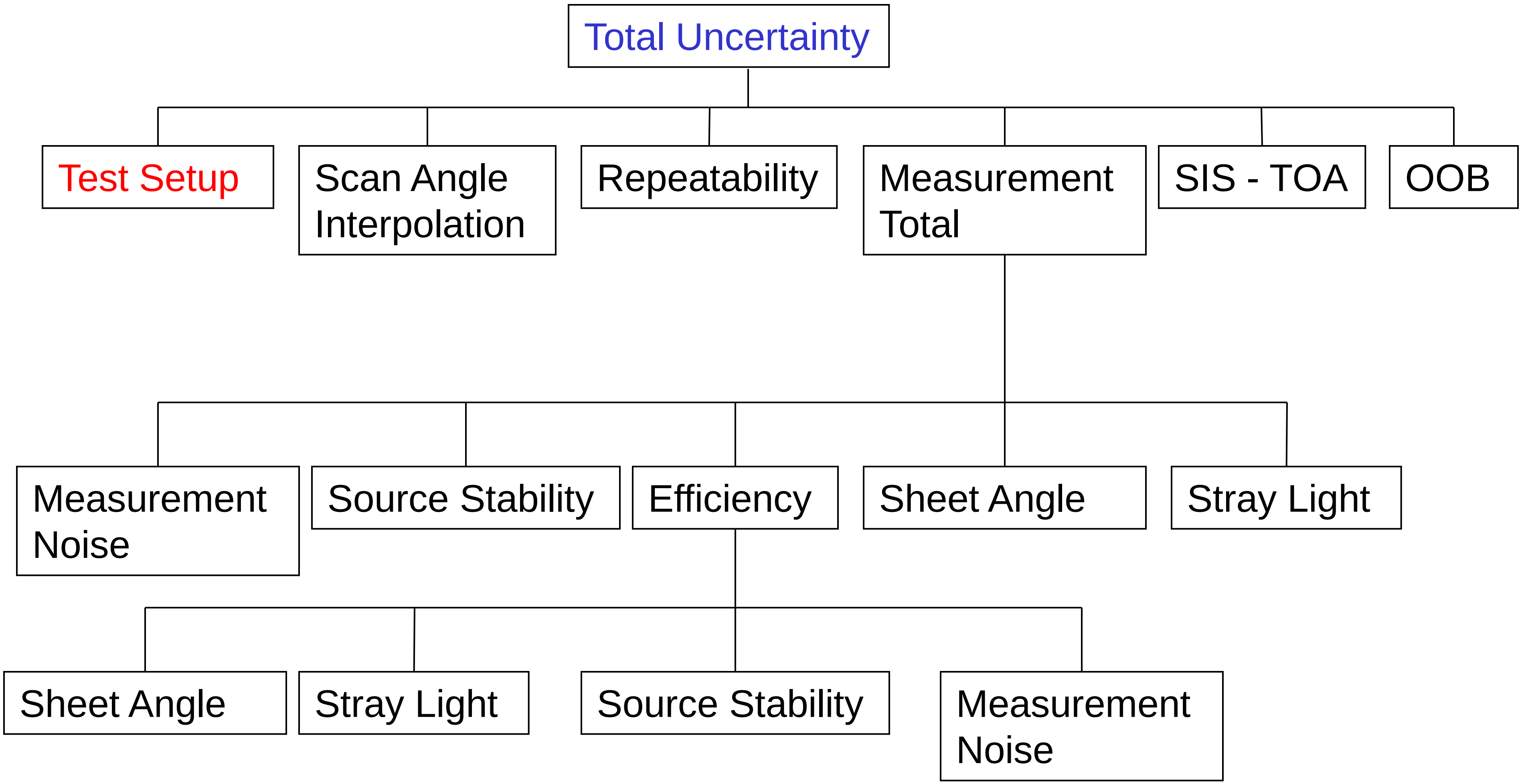
Model / Measurement Comparison

Comparing sensor level test results with model output

- Raytheon FRED model results compared to measurement (BVONIR)
- Results are generally consistent for most bands
  - Some differences observed in M4 and M6



Uncertainty Tree



Polarization Factor Uncertainty

Polarization uncertainty – maximum over HAM sides, detectors, and scan angles [in %]

	I1	I2	M1	M2	M3	M4	M5	M6	M7
Measurement noise	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Source stability	0.03	0.06	0.00	0.00	0.00	0.04	0.07	0.09	0.06
Stray light	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Sheet angle	0.01	0.04	0.06	0.03	0.02	0.02	0.04	0.04	0.04
Efficiency	0.00	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.00
Measurement total	**0.03**	**0.07**	**0.06**	**0.03**	**0.02**	**0.05**	**0.08**	**0.10**	**0.07**
Repeatability	0.04	0.01	0.03	0.03	0.03	0.06	0.02	0.01	0.01
Scan angle interpolation	0.04	0.07	0.03	0.02	0.04	0.05	0.09	0.05	0.07
SIS – TOA	0.20	0.19	0.34	0.05	0.11	0.05	0.09	0.01	0.03
OOB	0.00	0.00	0.06	0.04	0.08	0.00	0.00	0.00	0.00
Test setup	0.20	0.10	0.14	0.12	0.14	0.10	0.13	0.09	0.10
Total	**0.28**	**0.22**	**0.38**	**0.14**	**0.20**	**0.13**	**0.19**	**0.14**	**0.13**
Specification	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**

J1 Polarization Impact Assessment

A waiver for polarization non-compliances (M1 – M4) is pending

Waiting for NASA / NOAA impact assessments

Major effort is ongoing to understand the impact on J1 VIIRS products and provide corrective approaches

- JPSS science SMEs were selected for Ocean, Land and Aerosol disciplines to provide qualitative and quantitative impact assessments
- Three JPSS telecons were held to discuss a plan to complete impact assessment studies (30-Jan, 2-Feb, and 7-May)
- Three NOAA SDR telecons were held to discuss polarization detector dependence, comparisons to MODIS, and additional testing necessary for on-orbit mitigation (17-Mar, 2-April, and 16-Apr)
- Lessons learned based on MODIS instrument were discussed and analysis was performed
  - Polarization correction approach is available, and is being applied to some MODIS products
  - Results are promising based on MODIS experience

Quantitative Impact Assessment

Effort is ongoing based on SNPP VIIRS scenes to generate quantitative impact assessments

- JPSS Science Leads were assigned for each discipline:
  Ocean (G. Meister), Land (A. Lyapustin), and Aerosol (C. Hsu)
- Contrasted scenes were selected (favorable and worse case)
- Contaminated scenes were generated to assess the impact due to polarization
- Correction approach (if necessary) is available to enhance the quality of the products

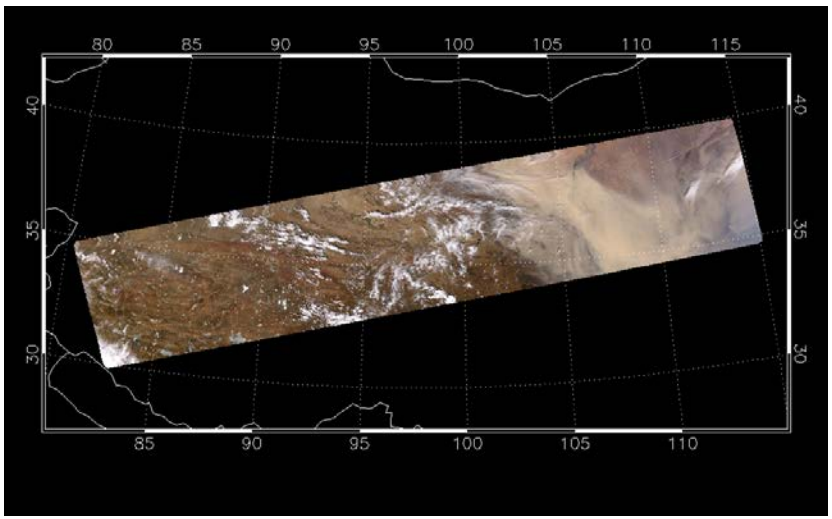
Additional J1 sensor testing (proposed post-TVAC)

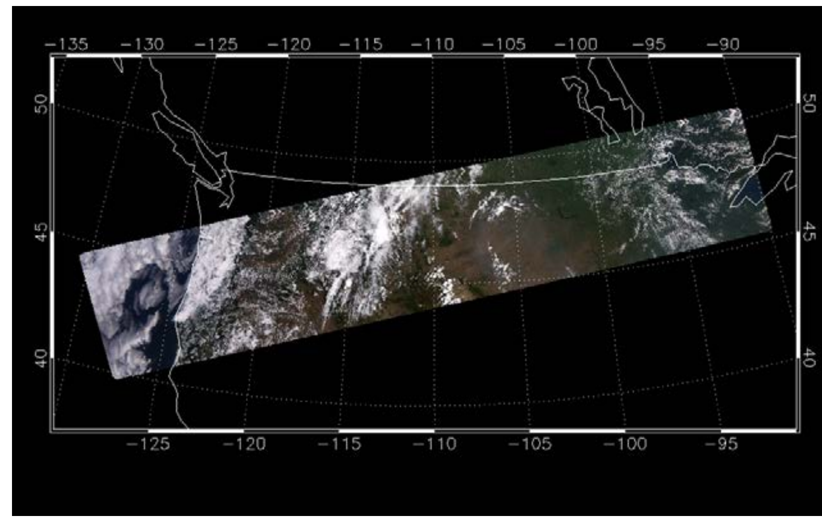
- Additional sensor level polarization testing for 5 scan angles (4 of which were untested previously)
- Spectral testing for M1 and M4 using T-SIRCUS (two scan angles and thirteen wavelengths)
- Data is expected to enhance the sensor polarization characterization and model predictions in support of the on-orbit corrections to the SDR / EDR products

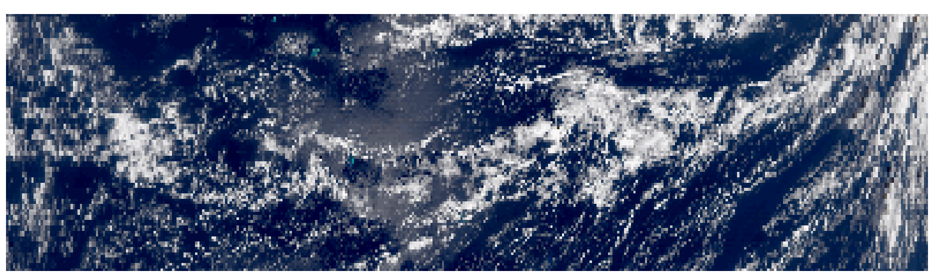
Assessment Using SNPP VIIRS Scenes

$$L_{TOA-t} = \frac{L_{TOA-m}}{M_{11}} - \frac{M_{12}}{M_{11}} Q - \frac{M_{13}}{M_{11}} U$$

L_{TOA-t} : true TOA radiance (desired quantity)
L_{TOA-m} : measured TOA radiance (VIIRS SDR)
Q, U : linear Stokes vector components, modeled from Rayleigh scattering and glint
M_{11}, M_{12}, M_{13} : fitted instrument characterization parameters (HAM, detector, and scan angle dependent)







Preliminary Impact Assessment

Preliminary assessments were presented for Ocean, Land and Aerosol products at a meeting on May 7th 2014

- Effect of J1 VIIRS polarization was applied to S-NPP VIIRS granules, using VCST J1 polarization characterization data (polarization factor, phase, and uncertainty)
- Preliminary results provided an estimate of the magnitude of the impact due to J1 polarization, and provided an encouraging path forward for product enhancements
- While Ocean products already have a polarization correction built into the processing algorithm, the final report will determine if there is a need to implement similar corrections in the Land and Aerosol products
- Final reports will include more VIIRS scenes and refined results upon which a waiver will be approved, and recommendations will be generated for the on-orbit VIIRS products cal/val and product quality enhancements

Conclusions

Polarization factors and phases were measured

- M1 – M4 above the sensor requirement for polarization factors
- Significant HAM side, scan angle, and detector dependence observed
- Results are consistent
  - Across testing configuration
  - With subassembly testing
  - With optical model

Uncertainty of polarization factor was also determined

- Maximum uncertainties per band were between 0.13 – 0.38 %
  - Specified maximum uncertainty is 0.5 %
  - Main contributors: test setup, SIS – TOA

Preliminary impact assessments from Science disciplines completed

Backup Slides

Test Overview

FP-11 Polarization Sensitivity (JPSS J1 VIIRS)

Sensor level test

VisNIR bands and DNB tested

Source – SIS100-2

Four configurations tested
- BVO777 polarizer sheet with and without the Sonoma filter (only at -8 degrees scan angle)
- BVONIR polarizer sheet with and without the Sonoma filter

Stray light levels investigated
- Data collected with source off
- Data collected with source on and “lollipop” obscuration in path

Efficiency of each configuration measured
- Second polarizer sheet of same type used to determine efficiency

Polarization sensitivity of VIIRS
- Data collected with each configuration at seven scan angles (only one for BVO777)
- Polarizer rotated from 0 to 360 degrees (in 15 degree increments)
- Measurements repeated at -8 degrees scan angle three times

Test Overview

FP-11 Polarization Sensitivity (JPSS J1 VIIRS)

After nominal testing was completed, special tests were conducted before the test configuration was broken

Configurations tested (all at -8 degrees scan angle)

- Removed cross hairs from aperture stop
  - BVONIR polarizer sheet with and without the Sonoma filter
- Blocked upper and lower half of VIIRS aperture
  - BVONIR polarizer sheet with and without the Sonoma filter
- Replaced blocking filter with the Hoya filter
  - BVONIR polarizer sheet
- Repeated testing during tear down of external baffling
  - BVONIR polarizer sheet with the Sonoma filter only

Compare to nominal testing at -8 degrees scan angle

Test Overview

ETP-078 Polarization Sensitivity (JPSS J1 VIIRS)

Aft Optics Assembly (AOA) subassembly test

VisNIR bands tested

Source – SIS100-2

Four configurations tested

- BVO777 polarizer sheet with and without the Sonoma filter
- BVONIR polarizer sheet without the Sonoma filter
- MOXTEK polarizer without the Sonoma filter

Efficiency of each configuration measured

- Second polarizer sheet of same type used to determine efficiency
- Efficiency not measured with the MOXTEK polarizer

Polarization sensitivity of VIIRS

- Polarizer rotated from 0 to 360 degrees (in 15 degree increments)
- Measurements repeated four times (twice with the MOXTEK polarizer)

Methodology

Model the dn as a Fourier series

$$dn(\alpha) = \frac{1}{2}c_0 + \sum_{n=1}^{4} c_n \cos(n\alpha) + \sum_{n=1}^{4} d_n \sin(n\alpha)$$

where

$$c_n = \frac{1}{\pi}\int_{-\pi}^{\pi} dn(\theta)\cos(n\theta)d\theta \qquad d_n = \frac{1}{\pi}\int_{-\pi}^{\pi} dn(\theta)\sin(n\theta)d\theta$$

This expression can be rewritten as

$$dn(\alpha) = \frac{1}{2}c_0\left[1 + \sum_{n=1}^{4} a_n \cos(2\alpha - \delta_n)\right]$$

where the polarization factor (amplitude) and phase are defined as

$$a_n = \frac{\sqrt{c_n^2 + d_n^2}}{\frac{1}{2}c_0\sqrt{a_2^{eff}}} \qquad \delta_n = \tan^{-1}\left(\frac{d_n}{c_n}\right)$$

The efficiency correction factor (a_2^{eff}) is defined in the same manner as a_n and derived from cross-polarizer data

Methodology

The final Stokes vector (recorded by VIIRS detectors) is related to the initial Stokes vector (entering VIIRS aperture) by the Meuller matrix

$$S_f = MS_i$$

This can be rewritten to isolate the Meuller matrix, or

$$S_f S_i^{-1} = M$$

The final stokes vector was derived from the sensor measurements. Using a model initial Stokes vector, one can determine the Meuller matrix components M_{12} and M_{13}:

$$M_{12} = a_2 \cos \delta_2$$

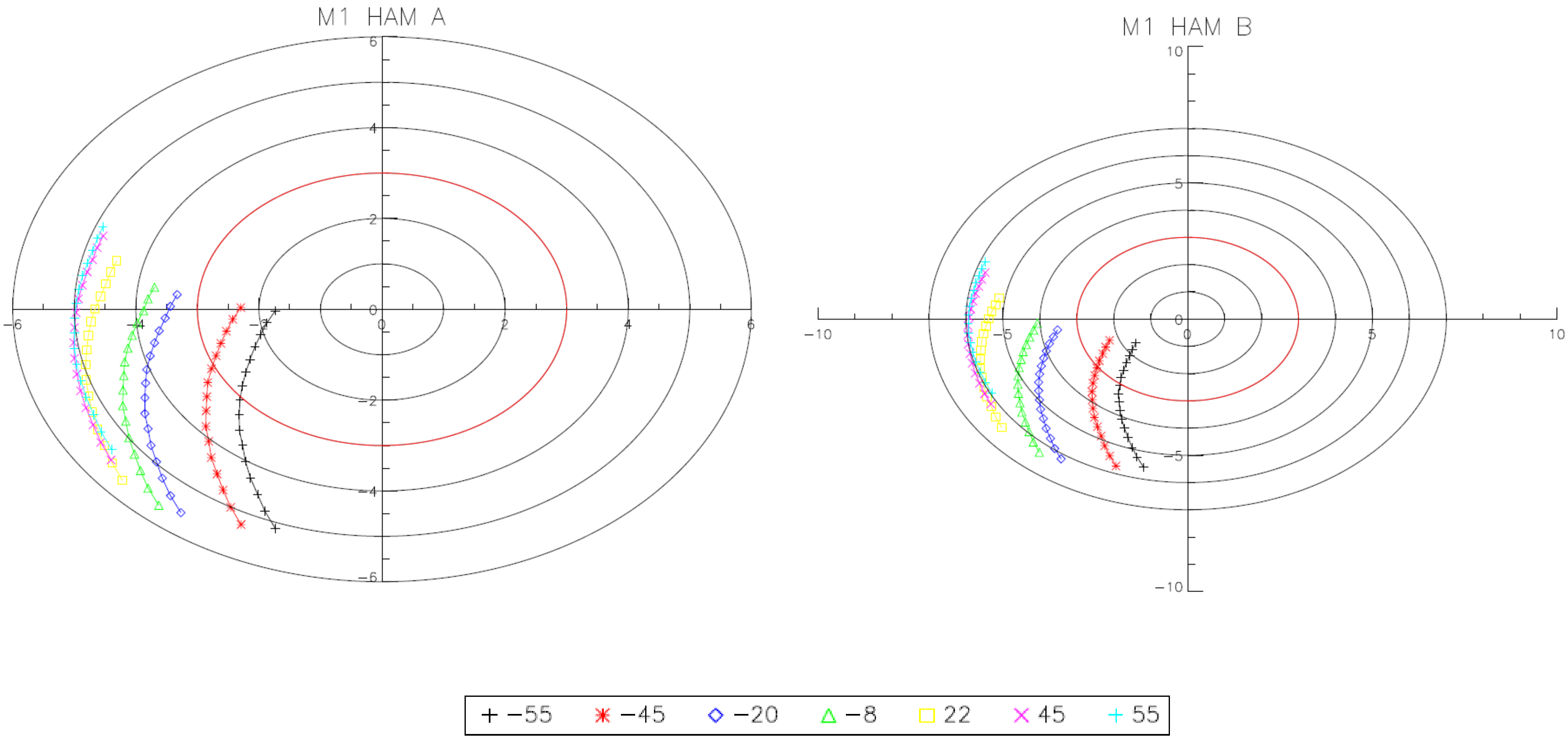
$$M_{13} = a_2 \sin \delta_2$$

where the polarization amplitude (a_2) and phase (δ_2) were defined on the previous slide

Polar Plots

Polarization factor and phase – polar plots (M1 HAM A)

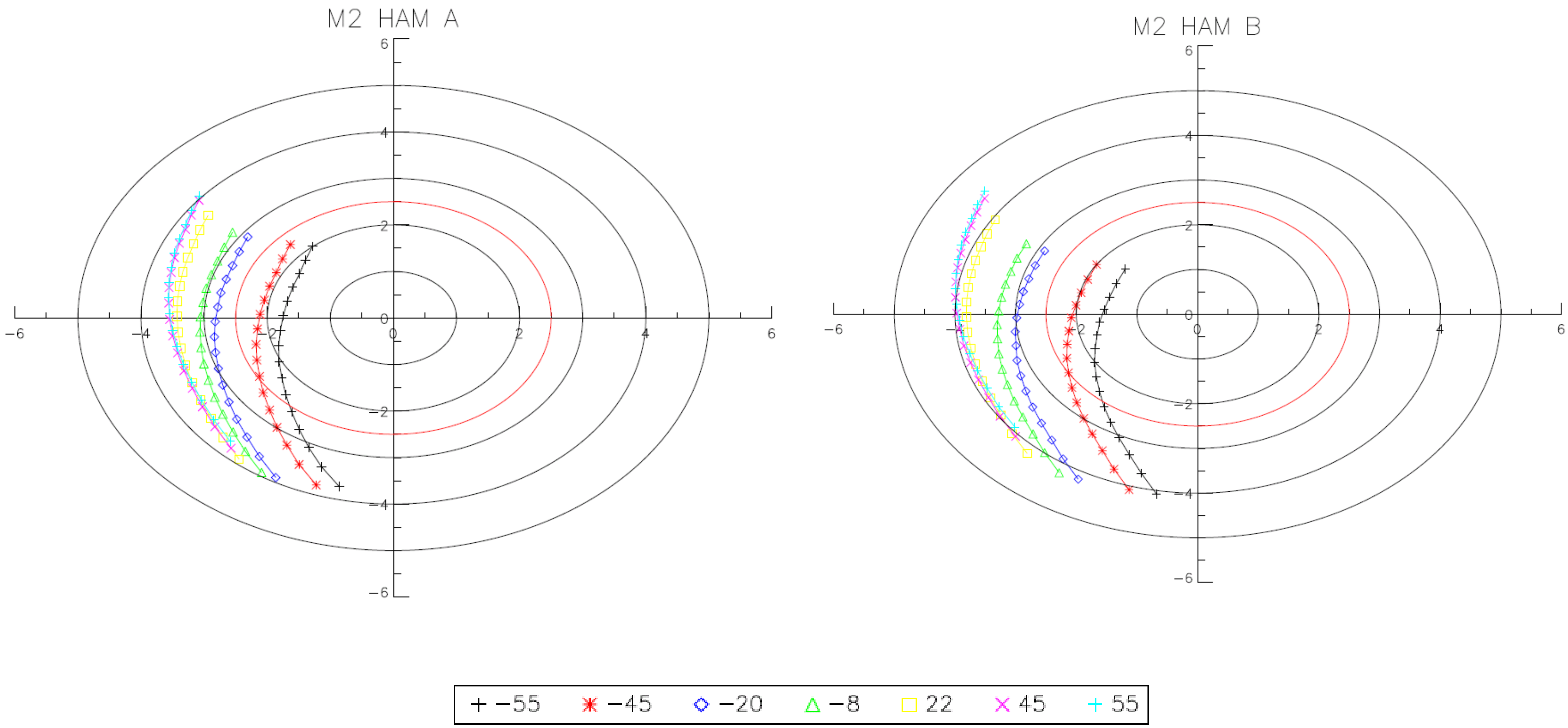
Specification in red



Polar Plots

Polarization factor and phase – polar plots (M2 HAM A)

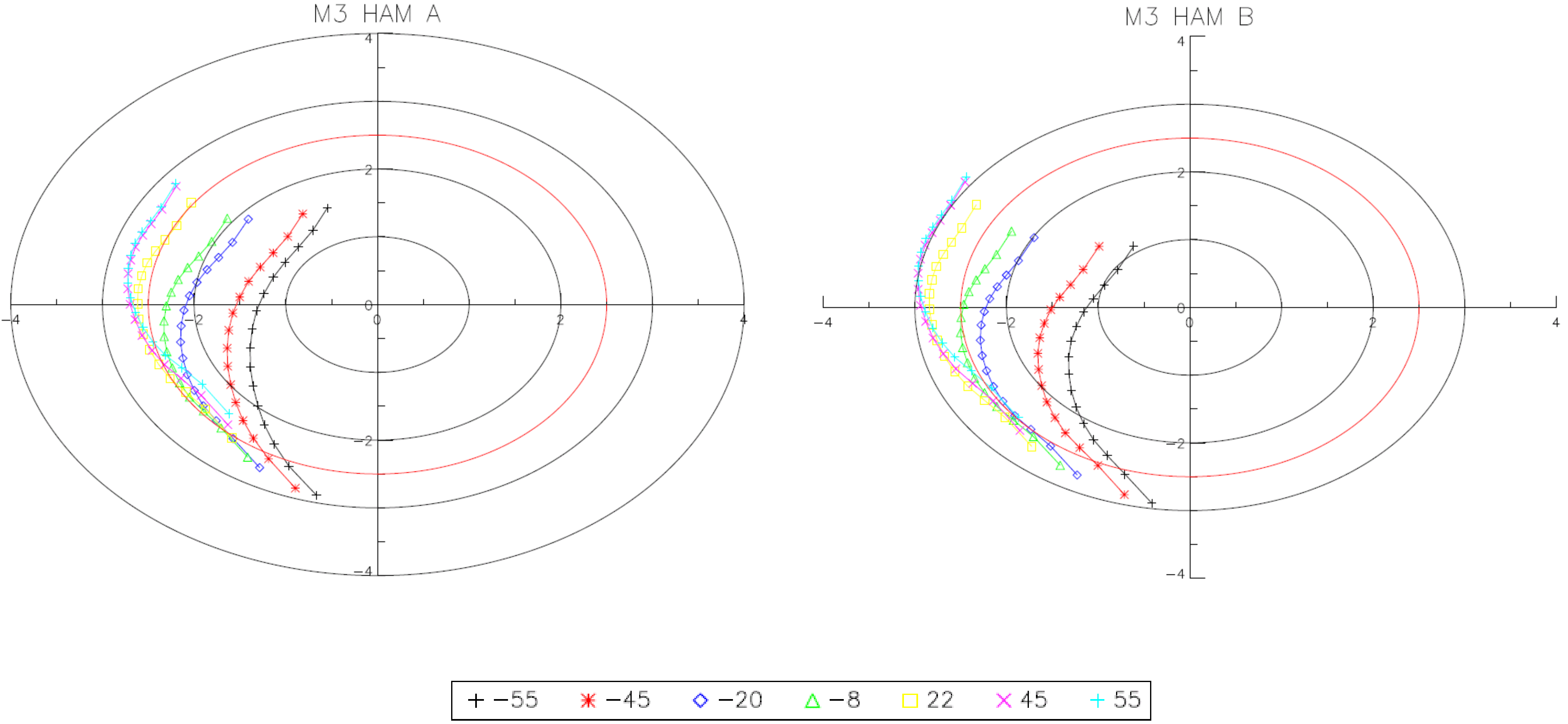
Specification in red



Polar Plots

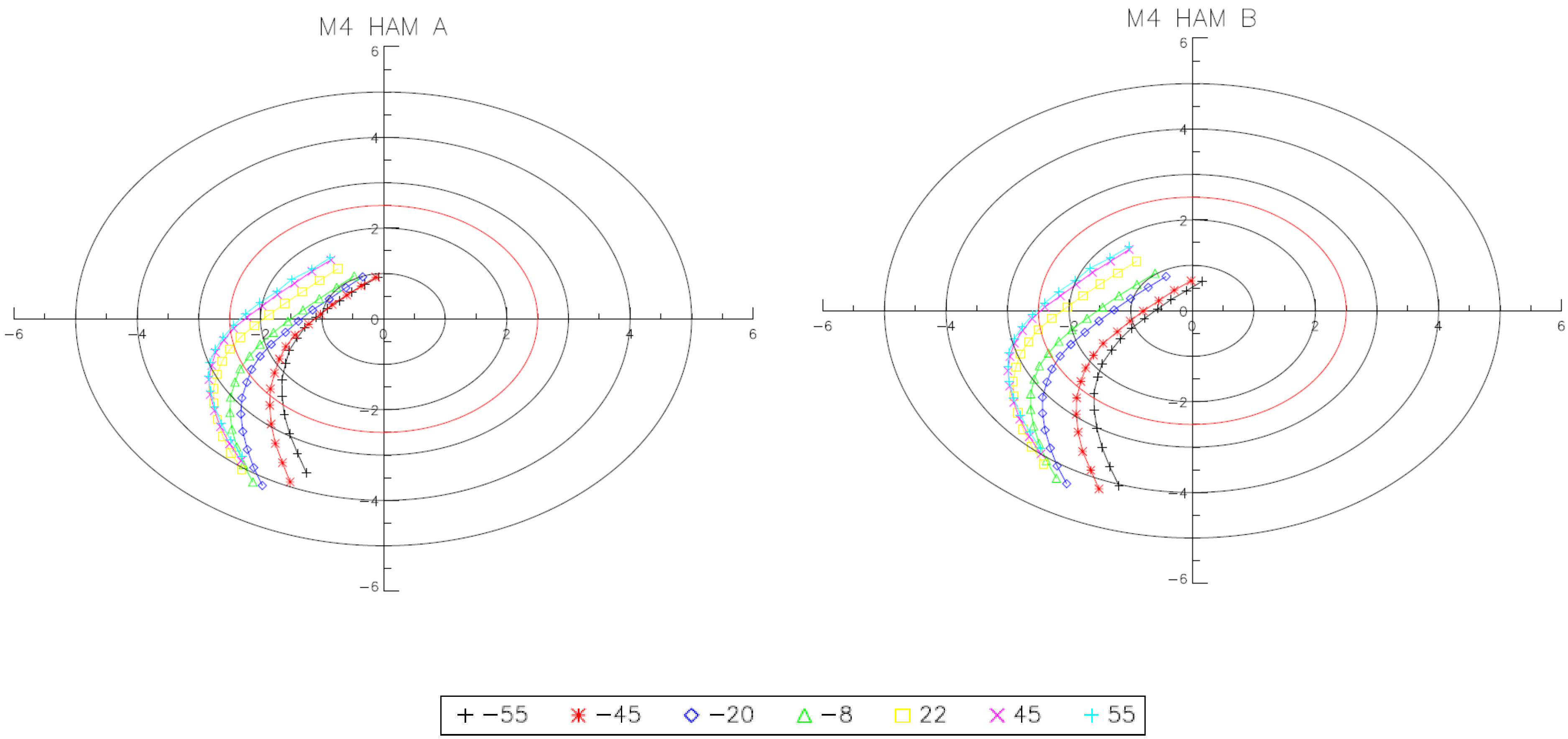
Polarization factor and phase – polar plots (M3 HAM A)

Specification in red



Polar Plots

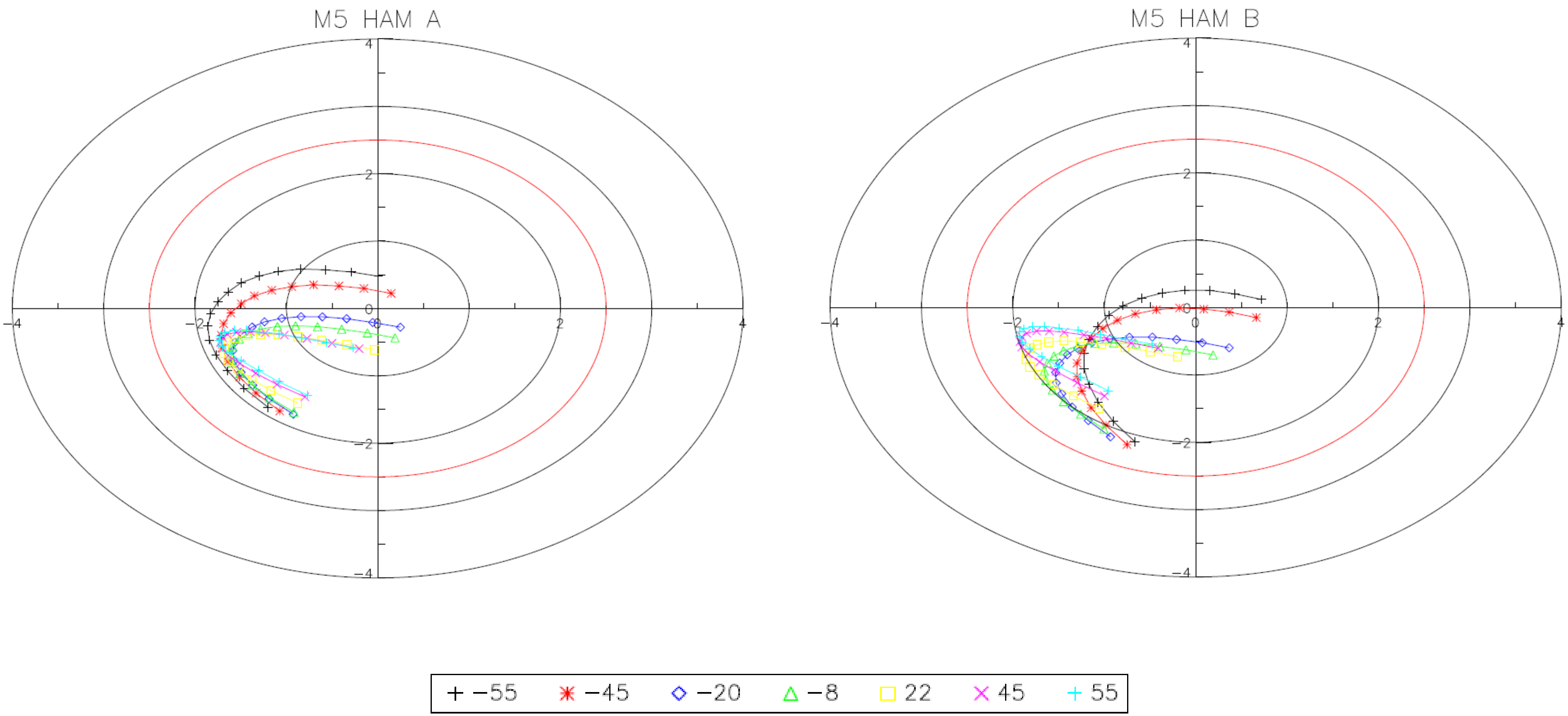
Polarization factor and phase – polar plots (M4 HAM A)
Specification in red



Polar Plots

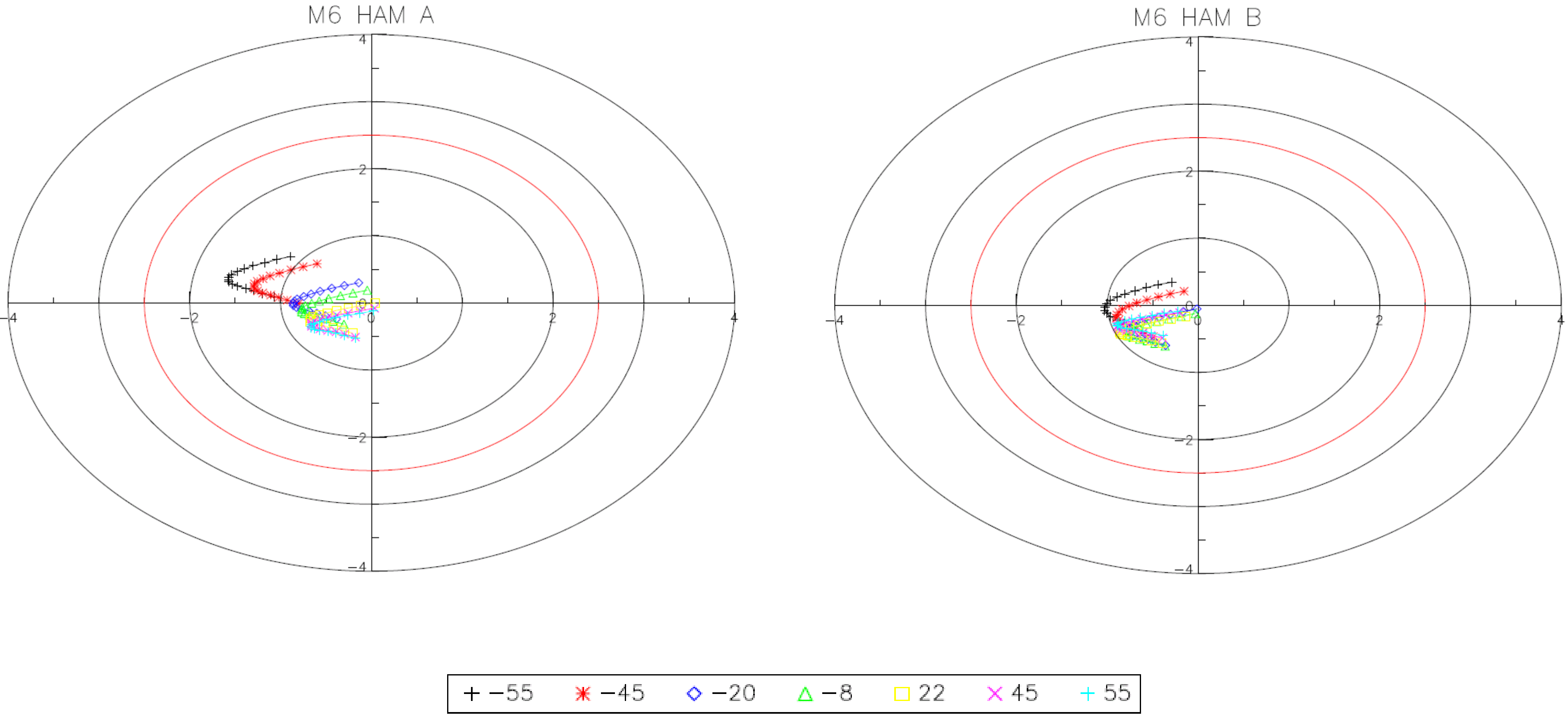
Polarization factor and phase – polar plots (M5 HAM A)

Specification in red



Polar Plots

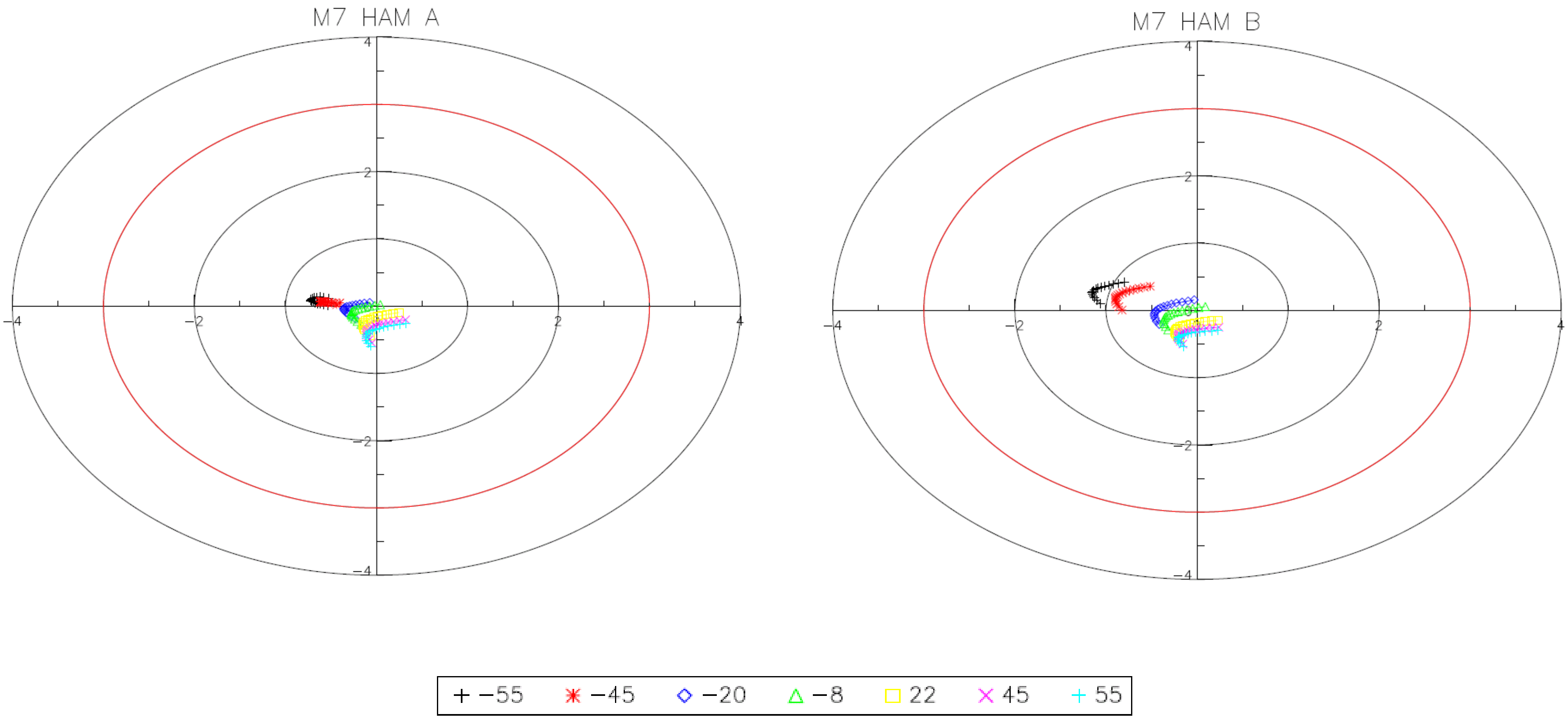
Polarization factor and phase – polar plots (M6 HAM A)
Specification in red



Polar Plots

Polarization factor and phase – polar plots (M7 HAM A)

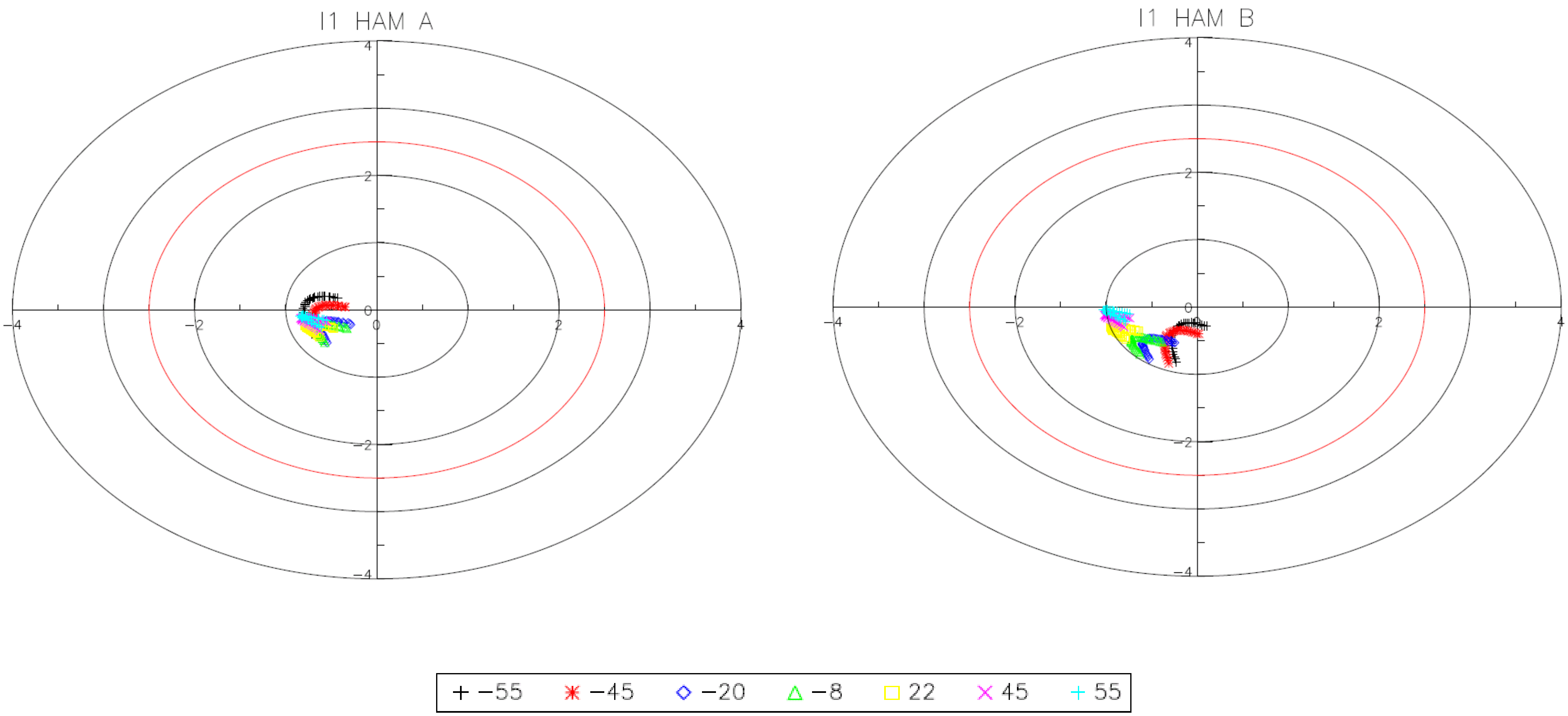
Specification in red



Polar Plots

Polarization factor and phase – polar plots (I1 HAM A)

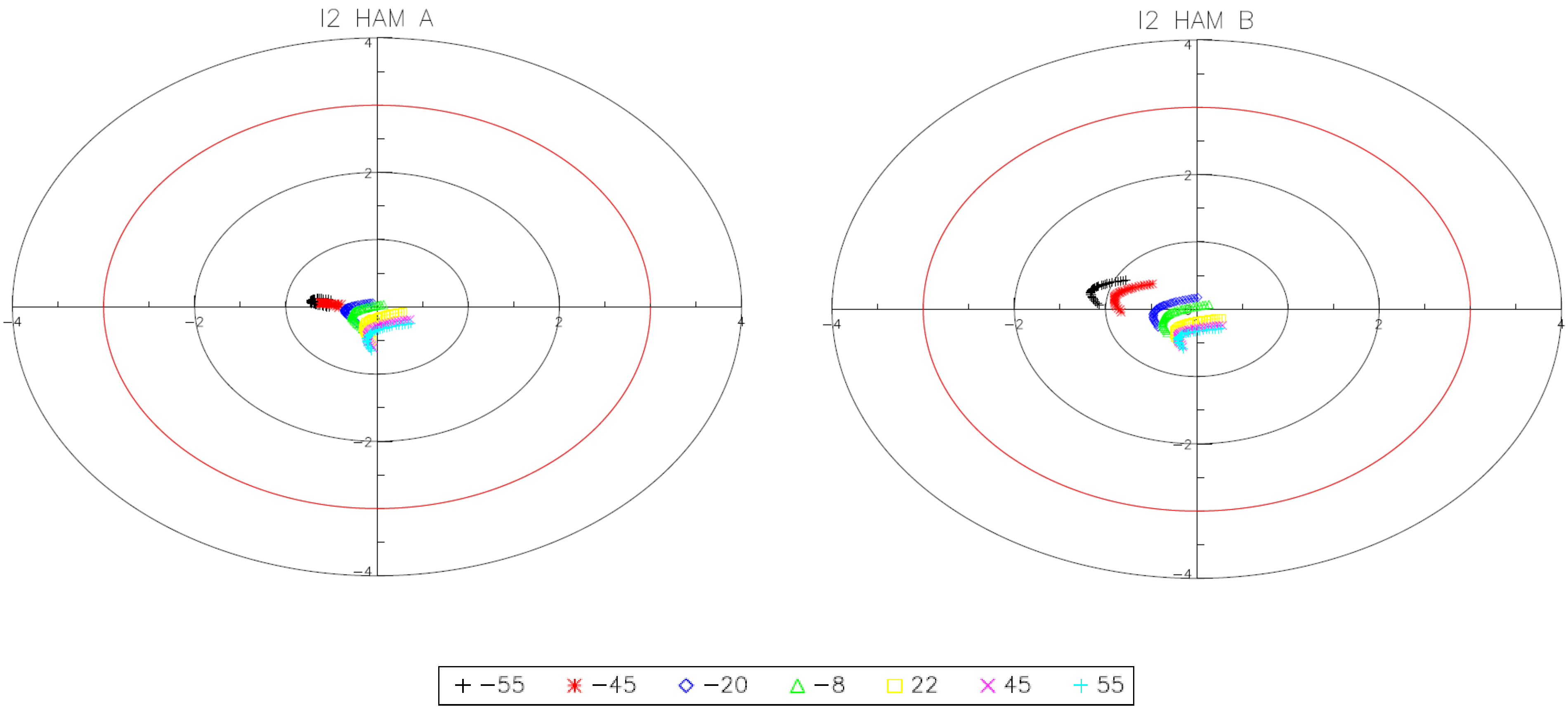
Specification in red



Polar Plots

Polarization factor and phase – polar plots (I2 HAM A)

Specification in red



Polar Plots

Polarization factor and phase – polar plots (DNB LGS HAM A)

Specification in red