Polarization in Coronagraphs

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Overview

- Polarization in WFIRST CGI
  - on-axis fast telescope
- Polarization in TPF-C
  - Off-axis fast telescope
- Polarization in off-axis fast UVO telescope
  - UV requirement impacts polarization performance.

WFIRST CGI Polarization

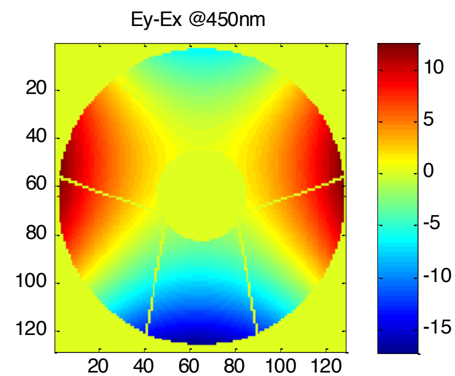
- Incidence angle on PM up to 12 deg. Angle up to 14 deg in CGI.
- f/1.2 primary
- Considered only the two main polarizations, not the cross polarization.
  - Hong says this is down by 3 orders of magnitude.
- Main polarization aberration is astigmatism.

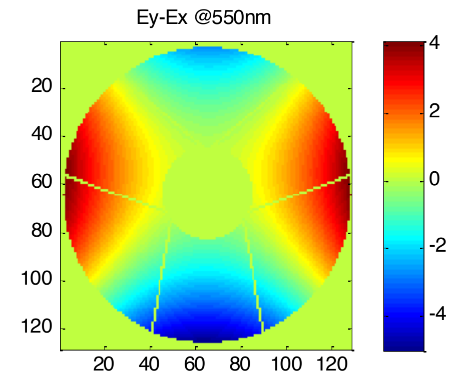
WFIRST Polarization PM+SM HRC Coating

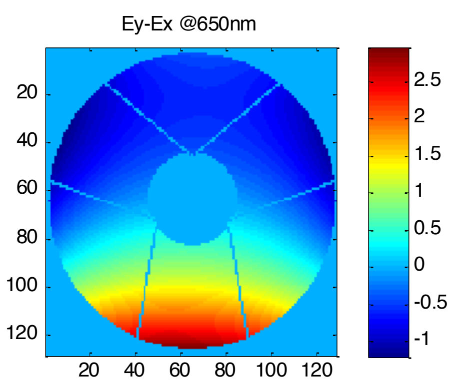
P-V of Differential WFE of Y and X polarizations

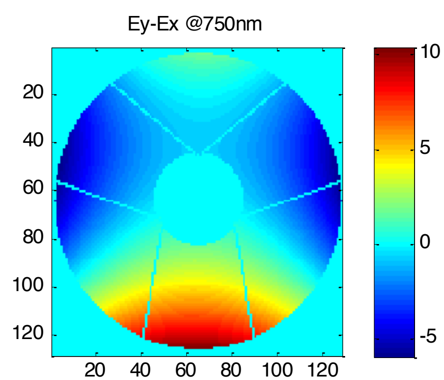
λ (nm)	Ey-Ex (nm)*
450	29.8
550	9.2
650	-4.2
750	-16.3
850	-27.5
950	-34.7

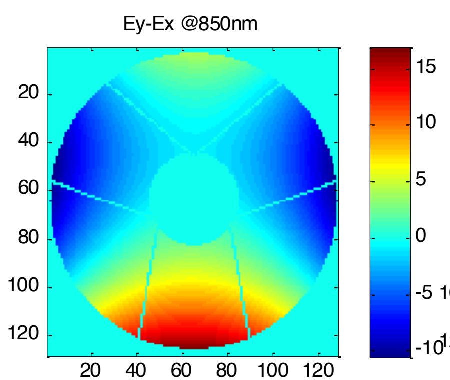
*P-V, Top-Bottom

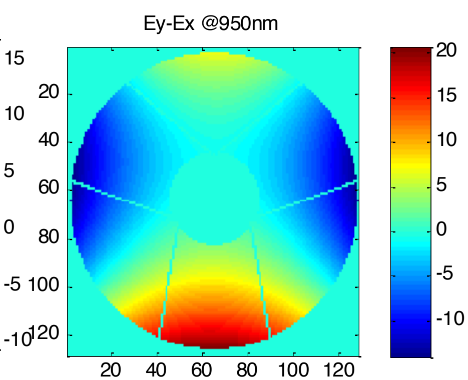








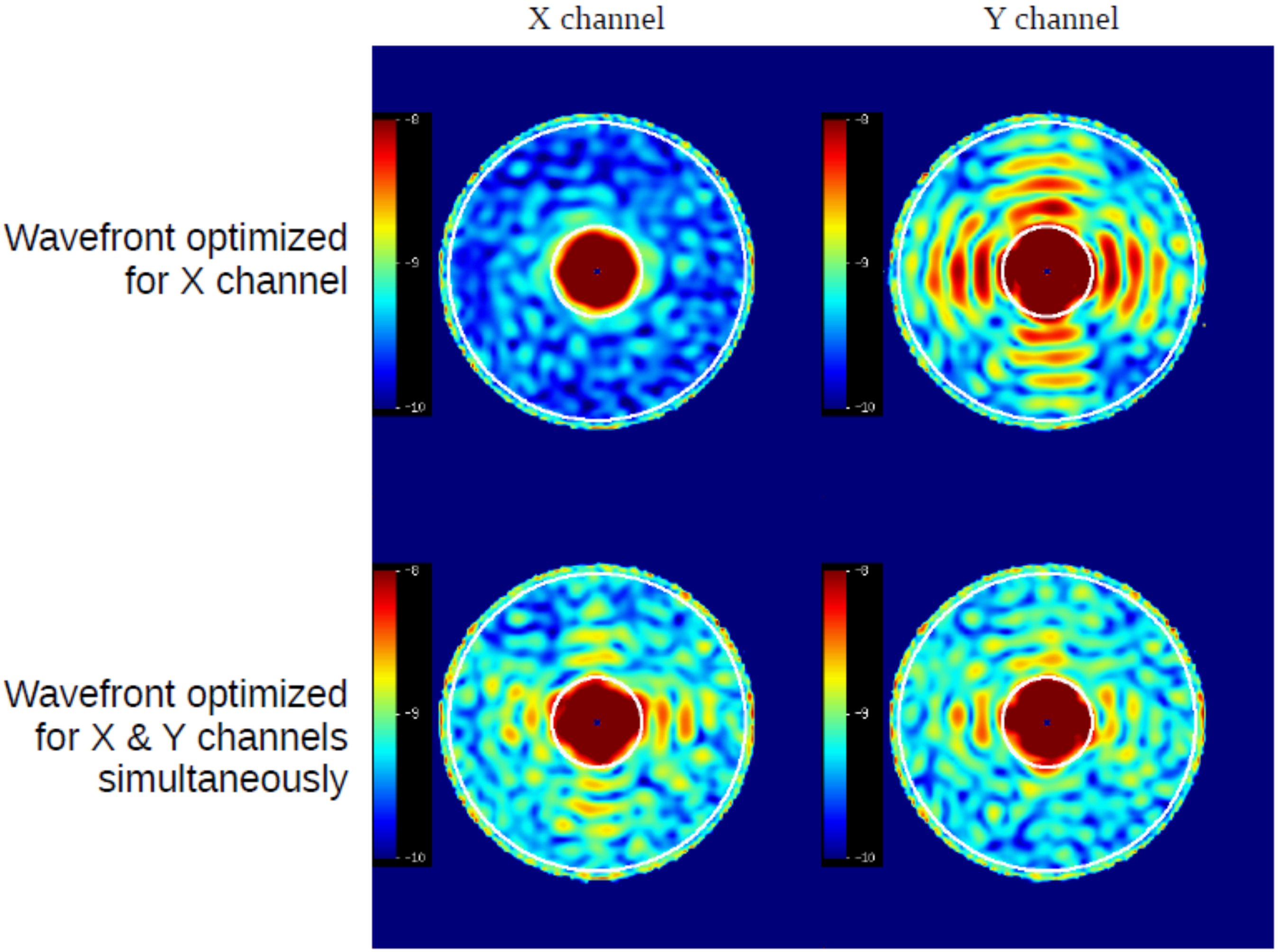




WFIRST CGI

HLC (20140623-139) Post-EFC with Polarization

λ = 523-578 nm, 0.4 mas RMS jitter, 1.0 mas star



Circles are r = 3 & 9.9 λ/D

WFIRST CGI

HLC (20140623-139) Post-EFC with Polarization

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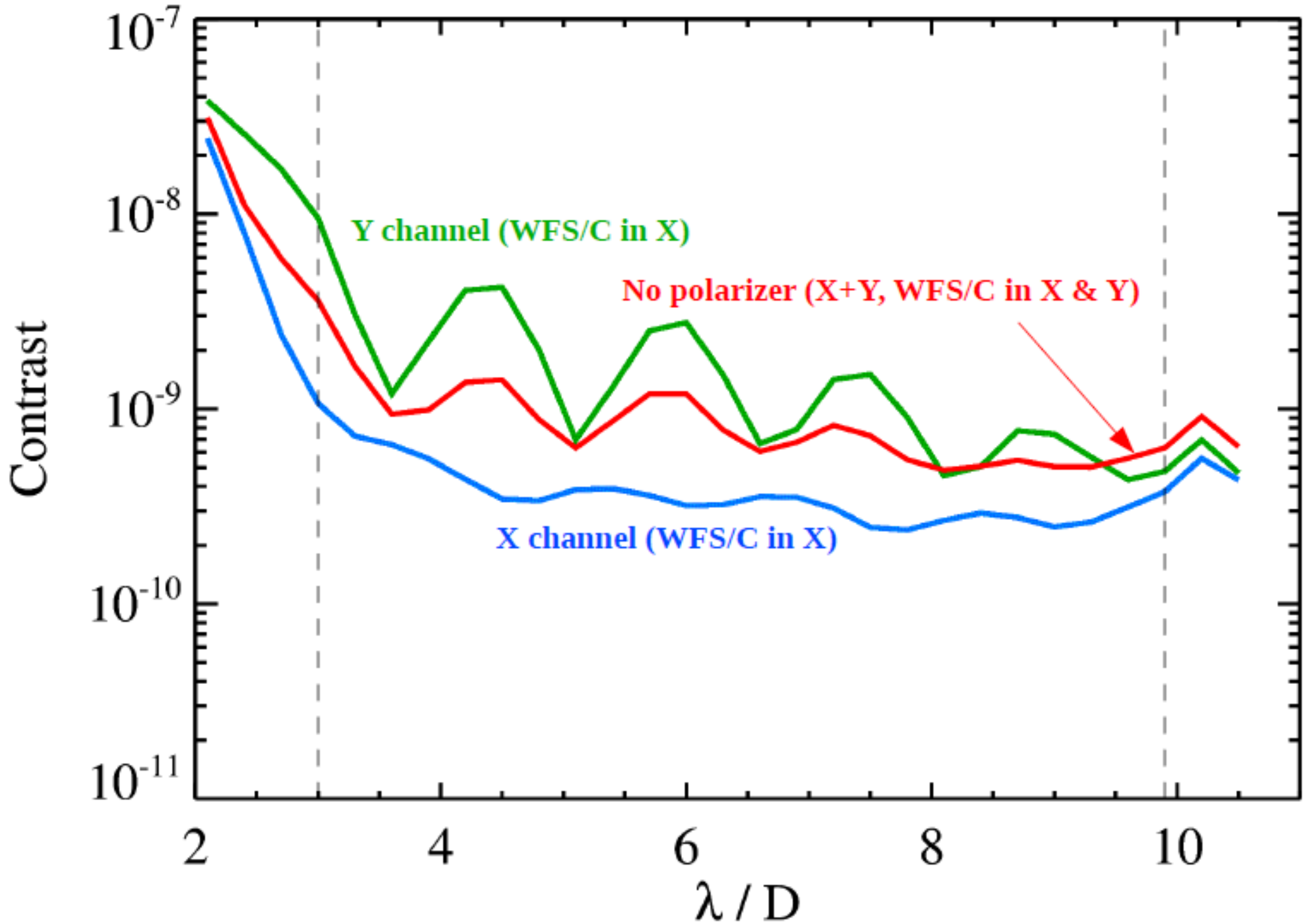
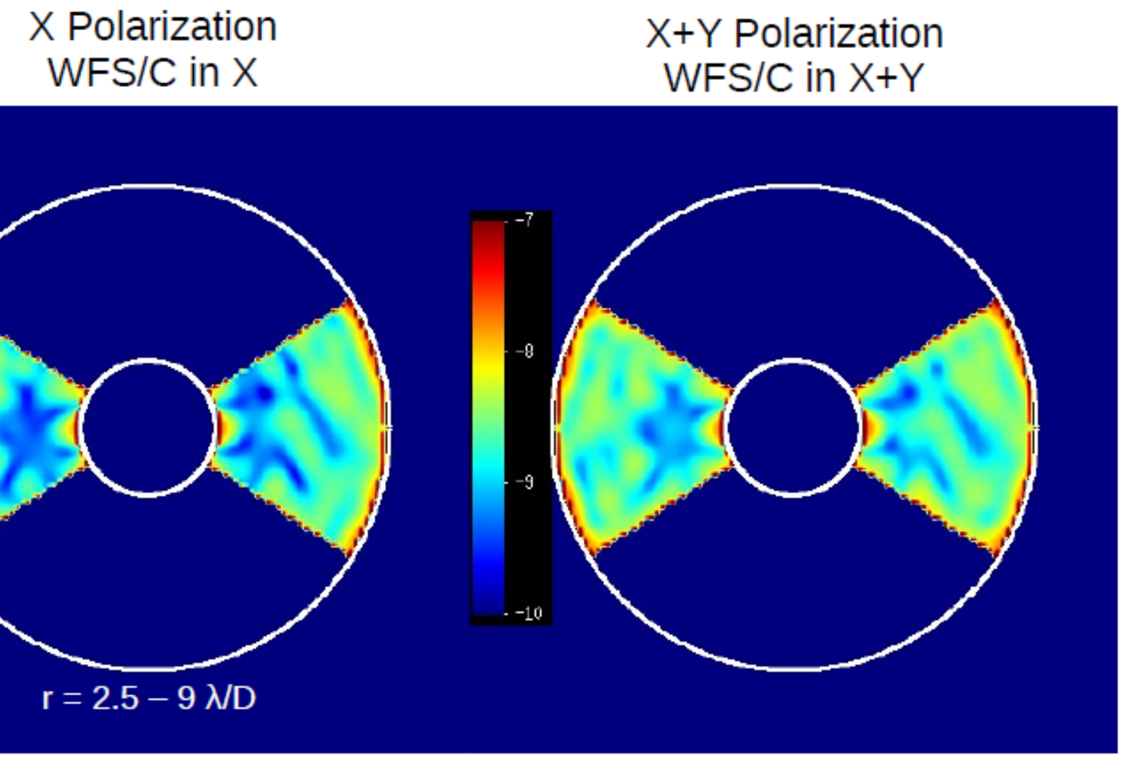


WFIRST CGI Shaped Pupil

AFTA Shaped Pupil + Lyot Stop

After EFC, aberrations, 728 - 872 nm, no jitter

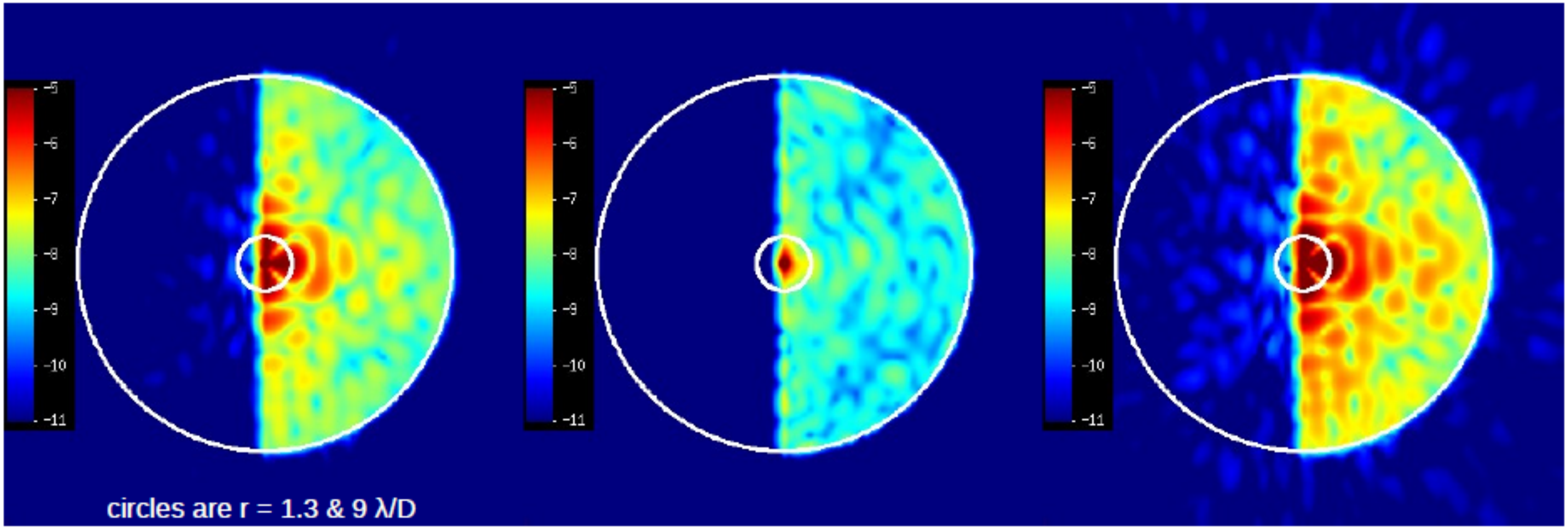


The shaped pupil + Lyot stop is only mildly sensitive to polarization errors. The primary aberration differences between the X and Y polarizations are astigmatism and tilt, both of which this design is relatively insensitive to. The polarization-induced aberrations are a few times less at 550 nm than 800 nm.

WFIRST PIAACMC

PIAACMC (Gen 2) Post-EFC (polarization, no jitter)
523 – 578 nm, half dark hole (r = 1.2 – 9 λ/D)

X+Y polarization Optimized for both	X polarization Optimized for X	Y polarization Optimized for X



1 DM used to form a half dark hole.

This PIAACMC design is only suitable for a single polarization.

TPF Terrestrial Planet Finder

Polarization compensating protective coatings for TPF-Coronagraph optics to control contrast degrading cross polarization leakage

Kunjithapatham Balasubramanian*, Daniel J. Hoppe, Pantazis Z. Mouroulis, Luis F. Marchen, and Stuart B. Shaklan

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Techniques and Instrumentation for Detection of Exoplanets II
San Diego, CA

August 02, 2005

Telescope requirements

- TPF-C telescope mirrors should provide
  - High reflectivity to ensure adequate throughput
  - 500 to 800nm minimum bandwidth;
    - 500nm to 1.05μm desirable
  - nm, sub nm surface quality, stability
  - Minimum polarization splitting due to mirror curvatures
    - 8m x 3.5m elliptical primary mirror encounters about 12 deg maximum angle of incidence
  - Excellent environmental stability over time

References:
Breckinridge, J. B. and Ben R. Oppenheimer, "Polarization effects in reflecting coronagraphs for white-light applications in astronomy", ApJ 600, pp.1091-1098, Jan 2004

Stuart B. Shaklan, L.F. Marchen, and J. J. Green, "The Terrestrial Planet Finder Coronagraph error budget" in this conference; Proc SPIE Vol 5905, 2005.

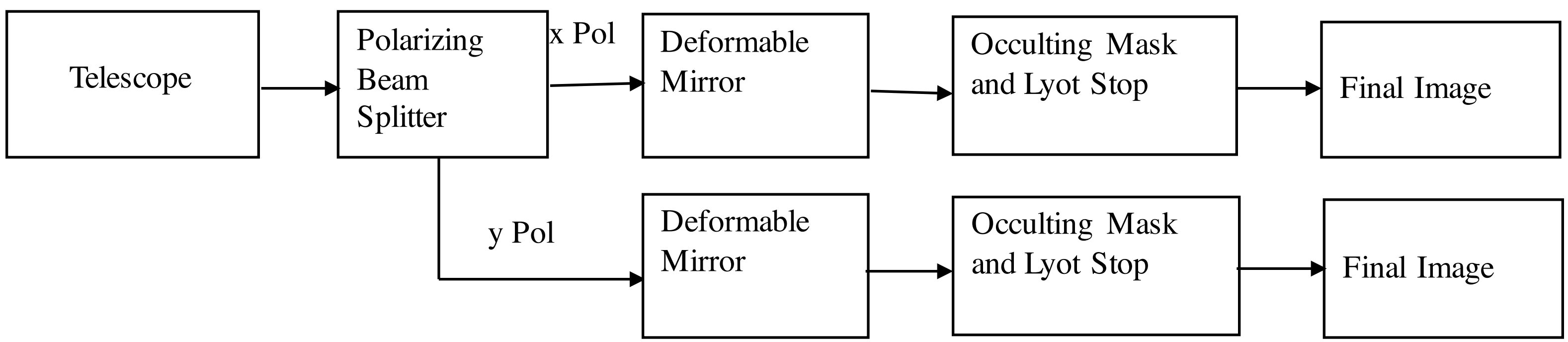
Pupil Fields

Total Field

Y polarization main term

Y polarization cross term

$$A_{xx}e^{i\phi_{xx}} + a_{xy}e^{i\phi_{xy}} + A_{yy}e^{i\phi_{yy}} + a_{yx}e^{i\phi_{yx}}$$

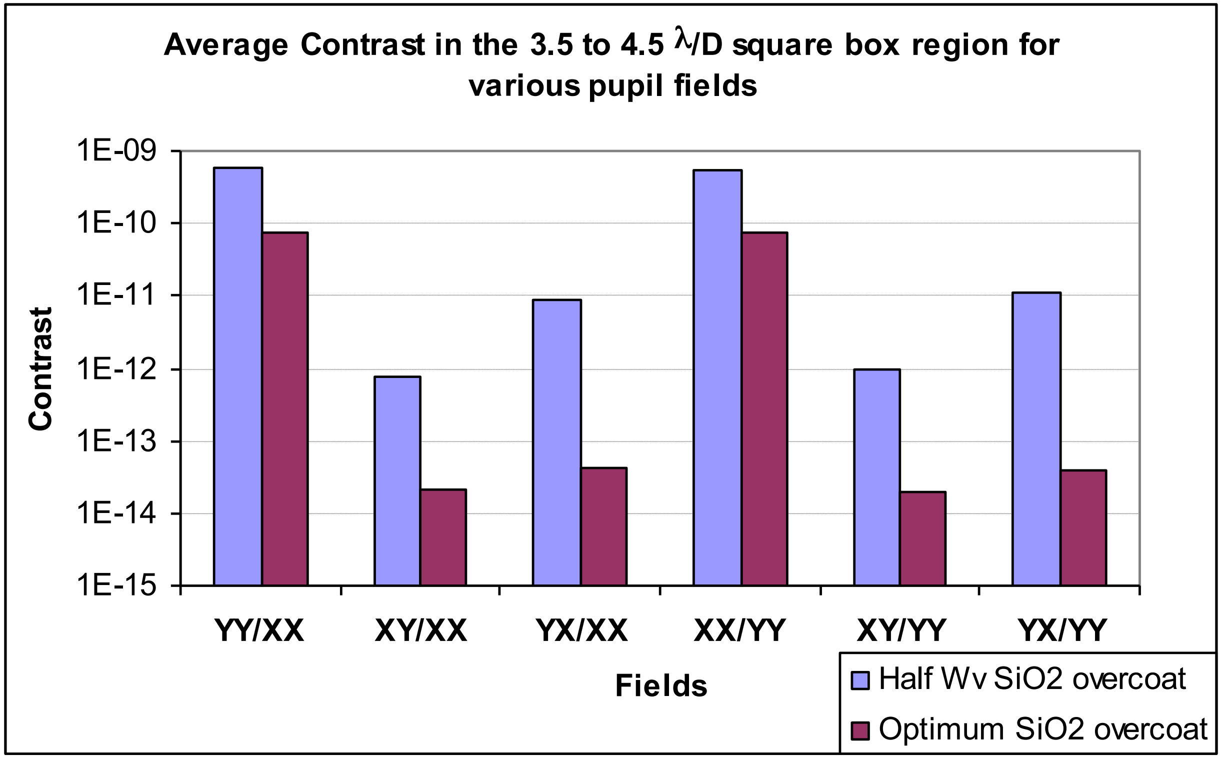


X polarization field after DM correction

$$1 + \left(\frac{a_{xy}}{A_{xx}}\right) e^{i(\phi_{xy} - \phi_{xx})}$$

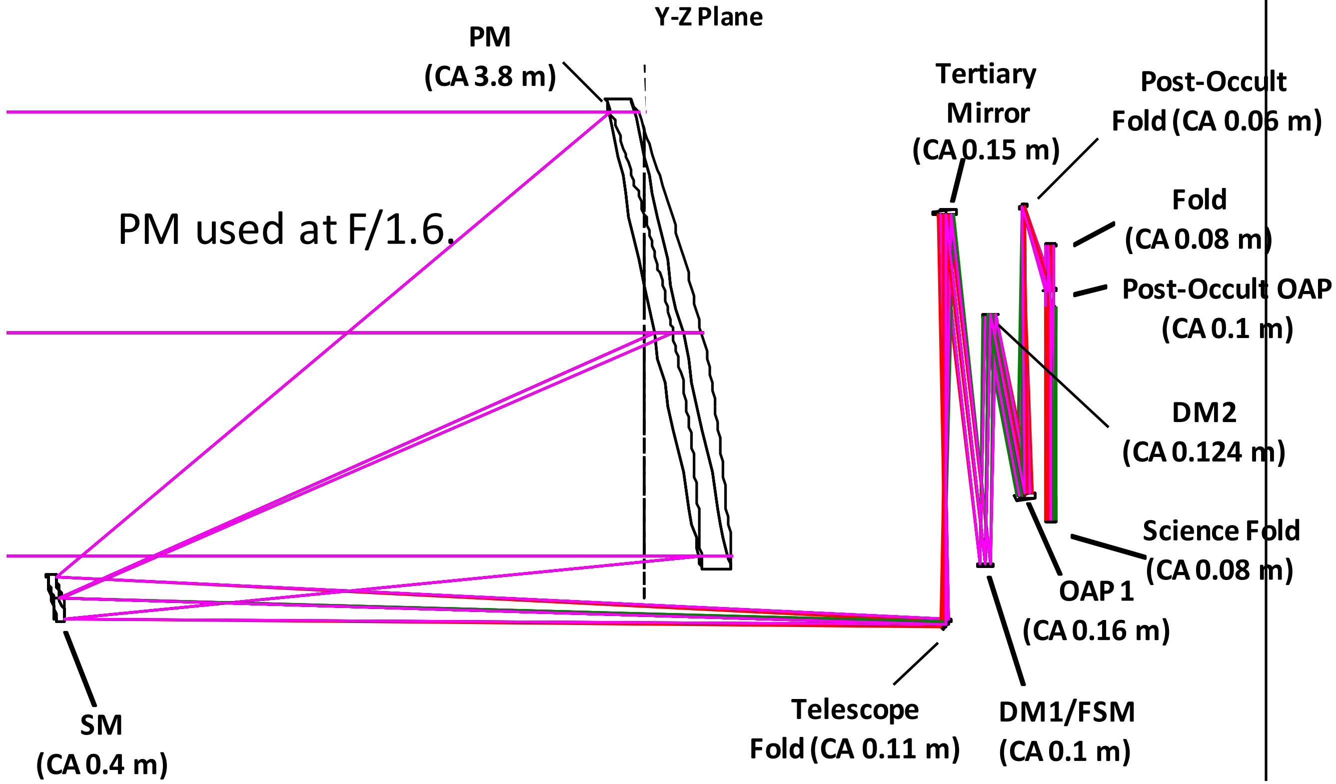
Leakage or residual due to cross term

Contrast for various field terms



Using linear sinc^2 mask.

Off-Axis Telescope



Design	Cassegrain
PM Diam	4 m
PM Clear Ap.	3.8 m
PM-SM separation	5.5 m along Z axis
PM ROC, conic	12.155 m, k=-1
PM Parent f/no	F/0.69
PM Angle of Incidence	2.8-19.9 deg
Off-axis displacement	2.5 m
SM ROC, conic	1.237 m, k=-1.3057

Coronagraph: radial 1-sinc^2 mask

Main driver on cross-pol

Deep UV to NIR space telescopes and exoplanet coronagraphs: a trade study on throughput, polarization, mirror coating options and requirements

Kunjithapatham Balasubramanian, Stuart Shaklan, Amir Give'on, Eric Cady and Luis Marchen

SPIE 8151 (2011)

Coatings studied

Table 3. Coatings Studied	
A1	25nmMgF_2/Al
A2	10nmMgF_2/70nmLiF/Al
A3	5nmMgF_2/10nmLiF/Al
B1	Si_3N_4/SiO_2/Si_3N_4/Al_2O_3/Ag
B2	Si_3N_4/SiO_2/Si_3N_4/Al_2O_3/Ag (B1 w/different thicknesses)
B3	11nmAlF_3/87nmLaF_3/Al
D	78nmLaF_3/58nmAlF_3/Al
F	30nmMgF_2/110nmLiF/Al
G	55nmMgF_2/90nmLiF/Al

Table 4. Different cases of coatings on the telescope mirrors

Cases Studied	PM	SM	3rd OAP	Approximate cut -off λ	average visible T through 5 mirrors
Case A	A1	A1	A1	110 to 120nm	52%
Case B	B1	B2	B2	350 to 400nm	92%
Case C	F	G	A	120 to 150nm	49%
Case D	B3	D	D	120 to 150nm	39%
Case E	F	F	F	120 to 150nm	39%
Case J	A2	A2	A2	110 to120nm	38%
Case K	A3	A3	A3	100 to 120nm	53%

Cross Polarization in off-axis design

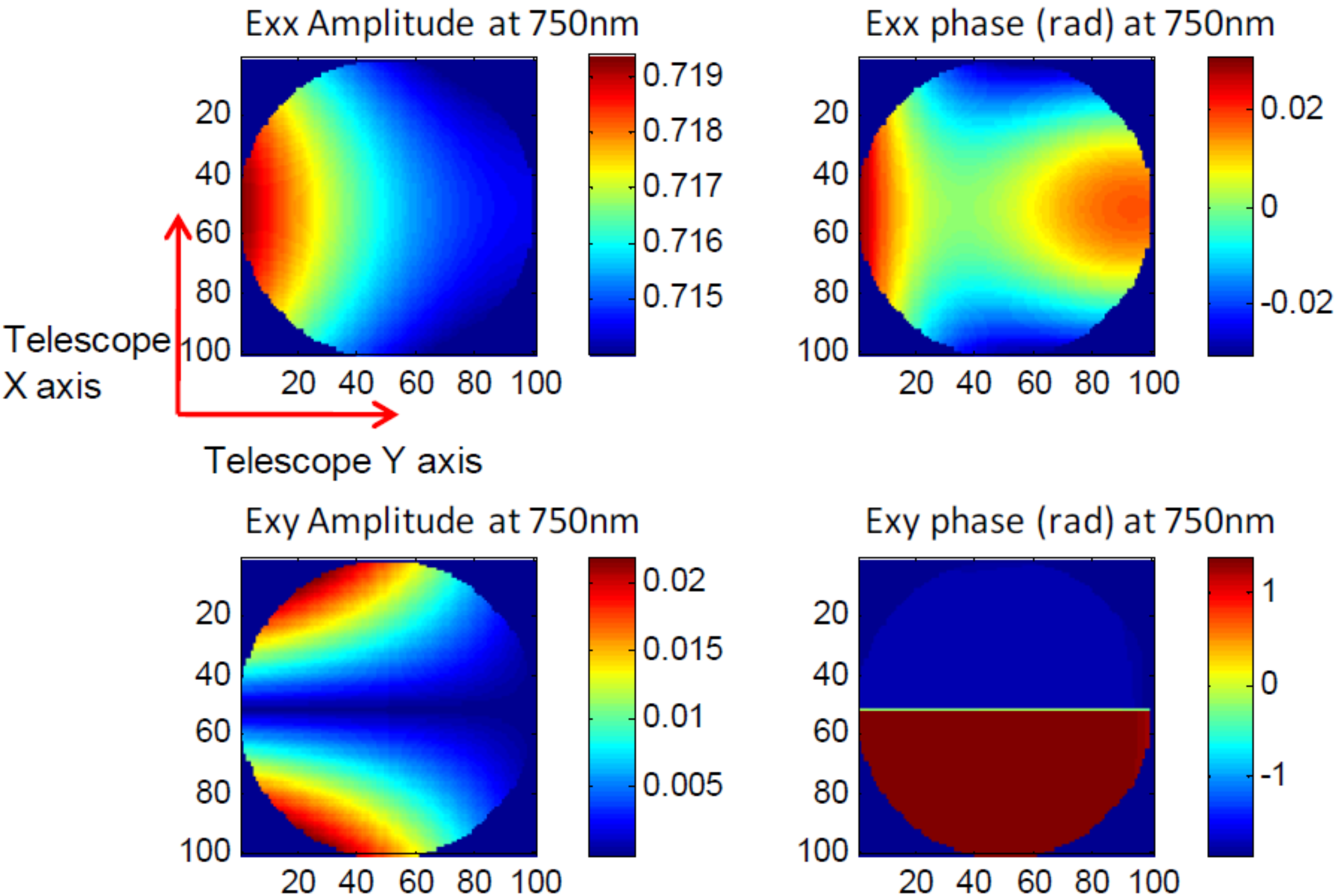
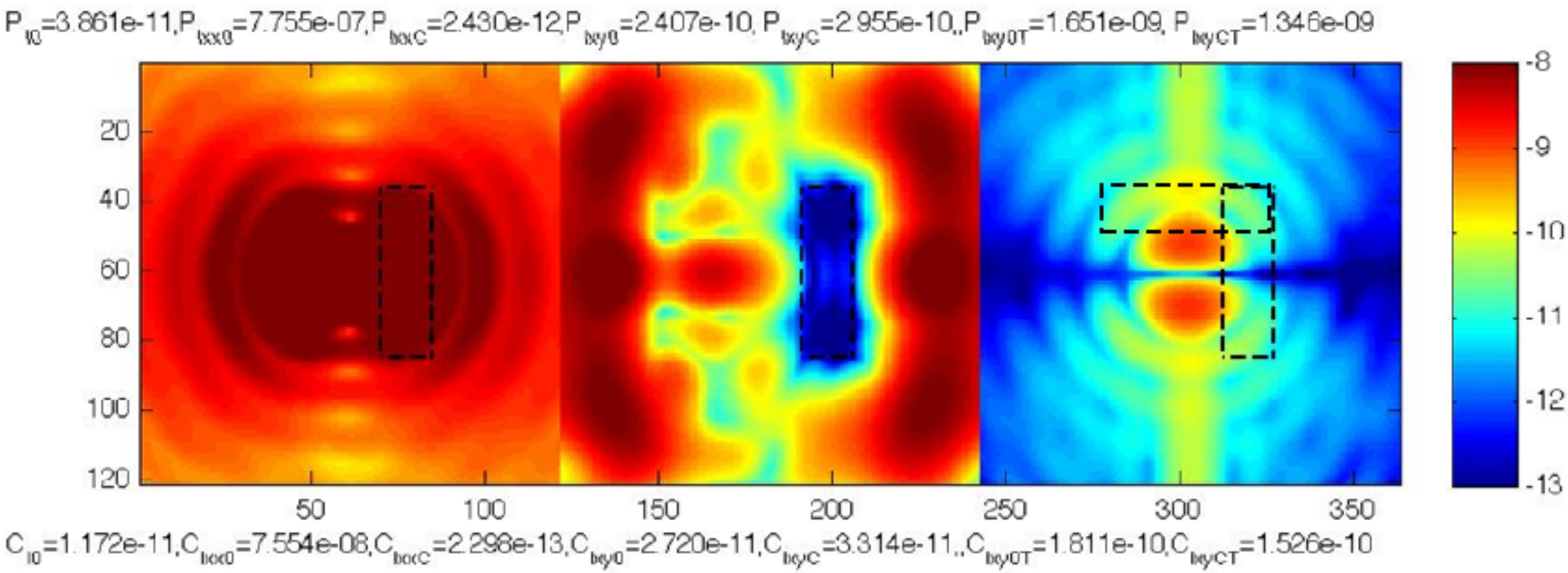


Figure 8. Exx and Exy field pupil maps with the telescope mirrors coated with 25nm MgF_2 protected Al

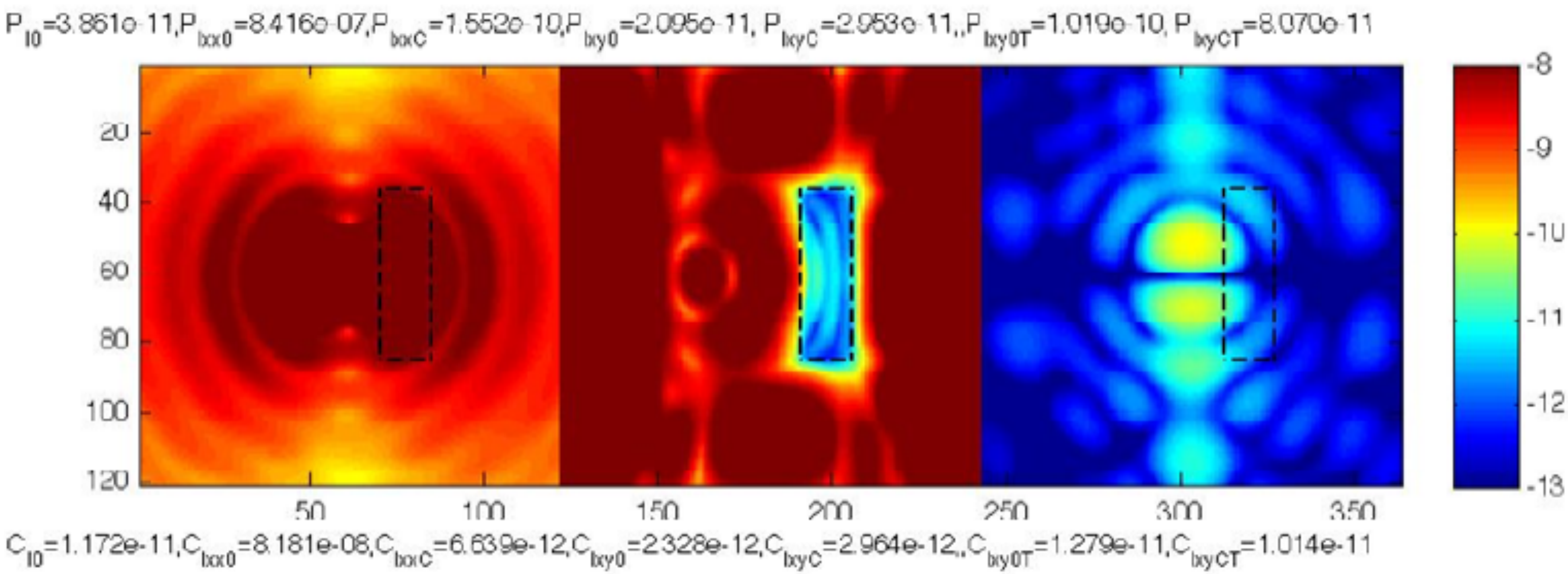
Cross Polarization bare aluminum



Uncorrected main term | Corrected main term | Cross term

UV Compatible but lots of leakage

Cross polarization, protected silver



Uncorrected main term | Corrected main term | Cross term

No UV signal, better leakage

Contrast in image plane, >2.5 λ/D

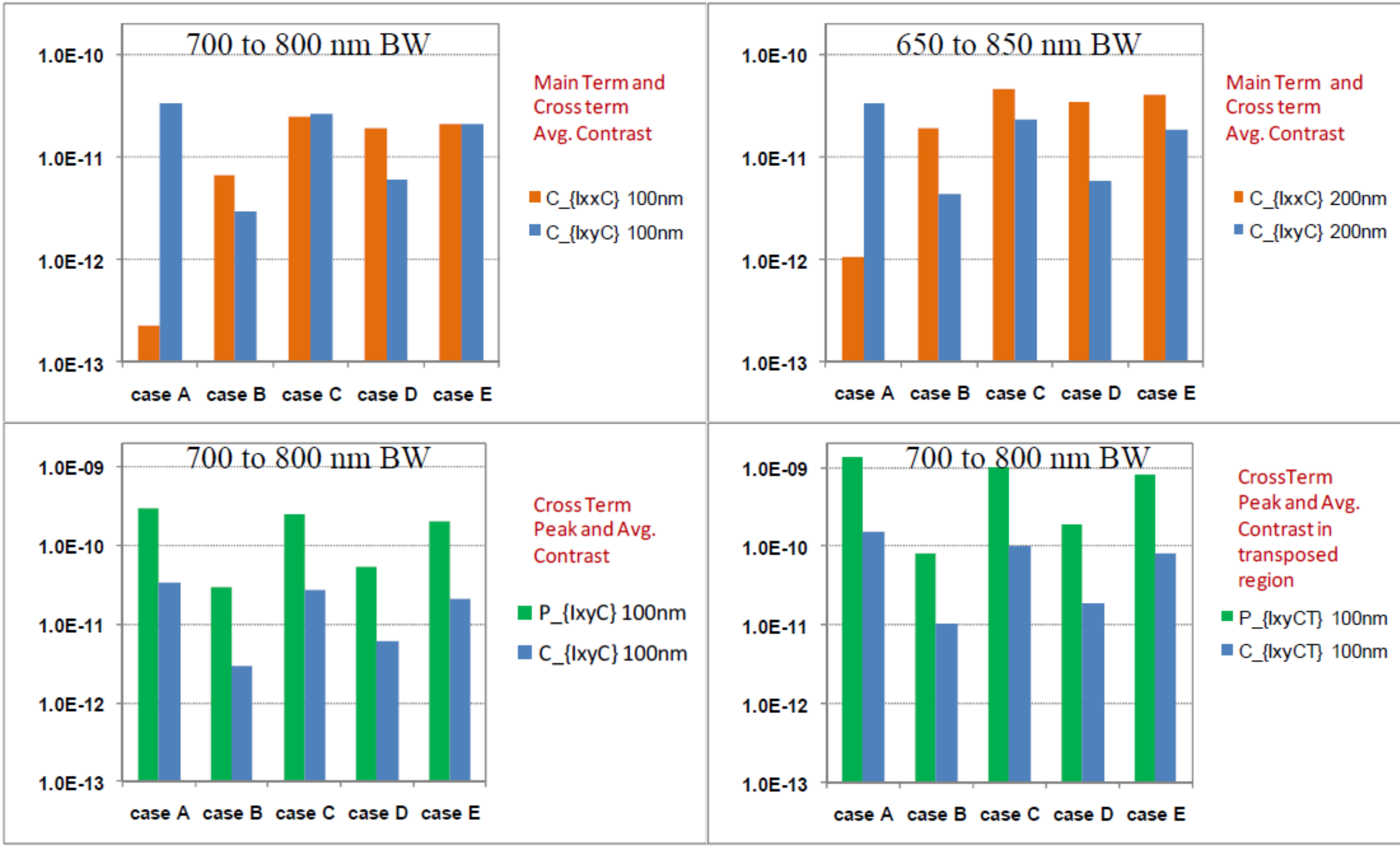


Figure 15. Average and peak contrasts in the dark hole region for various cases examined

Summary

- WFIRST shows that two separate polarization channels are required.
  - Cross-pol not analyzed but probably < 1e-11 level
- TPF-C shows that cross polarization contrast level is 1e-11 at 4 λ/D.
  - Not a big deal because it's fixed pattern, and there will be brighter background sources (e.g. Leakage from finite star diameter, exozodi).
- UVO off-axis telescope study showed that UV requirement significantly increases cross-pol.
  - Peak contrast > 1e-9 at 2.5 λ/D.
  - Without UV requirement, peak was <1e-10.
  - Max Angle of Incidence is 19 deg.