UV Coatings, Polarization, and Coronagraphy

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Presented to the LUVOIR & HabEx STDTs

11/10/16

Objectives

- Review of UV coatings and state-of-the-art
- Review of polarization aberration and the impact on coronagraphy
- Recent study results
  - HabEx
  - LUVOIR
- Work to be done

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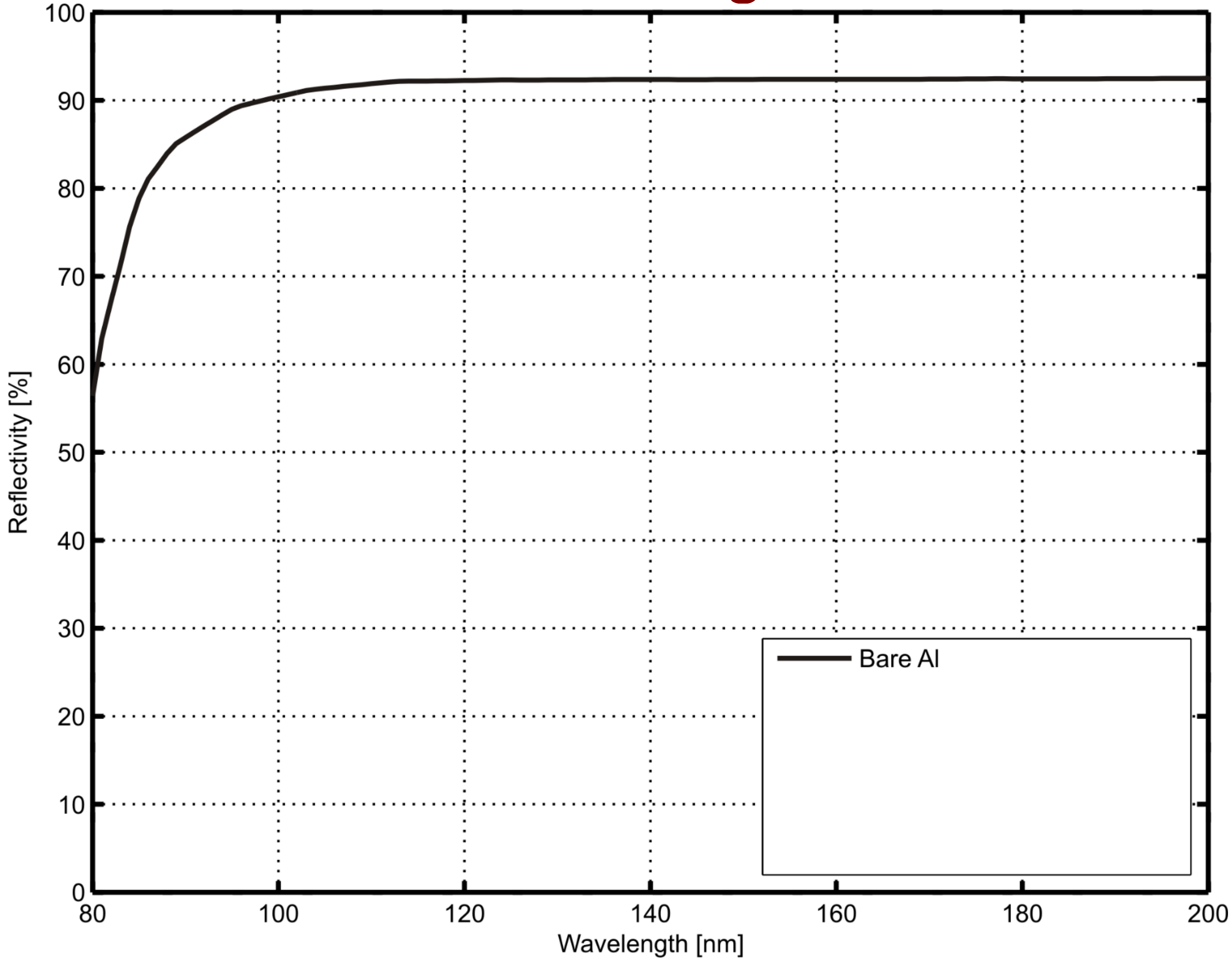
- Protective overcoats are used to prevent oxidation
  - Commonly fluoride overcoats, such as MgF_2, LiF, or AlF_3
  - Provide high reflectivity for wavelengths as short as ~110 nm
  - Shortward of 110 nm, reflectivity depends on material and deposition process

UV Coatings

- Al + MgF_2
  - New "hot" deposition process heats substrate to 220° C
  - Improved reflectivity (> 85%) above 120 nm
  - Cutoff occurs around 115 nm with limited reflectivity shortward
    - ~20% reflectivity at 100 nm
- Al + LiF
  - Lower cutoff than MgF_2, achieving 80% reflectivity as low as ~105 nm
  - LiF is hygroscopic
    - Performance degrades with exposure to water vapor in air
    - Would require dry purge on mirrors during ground operations, OR
    - Requires an additional protective overcoat which can further suppress reflectivity
- Al + AlF_3
  - Promising new coating with low cutoff like LiF, and stability of MgF_2

UV Coatings



100
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Reflectivity [%]
80
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120
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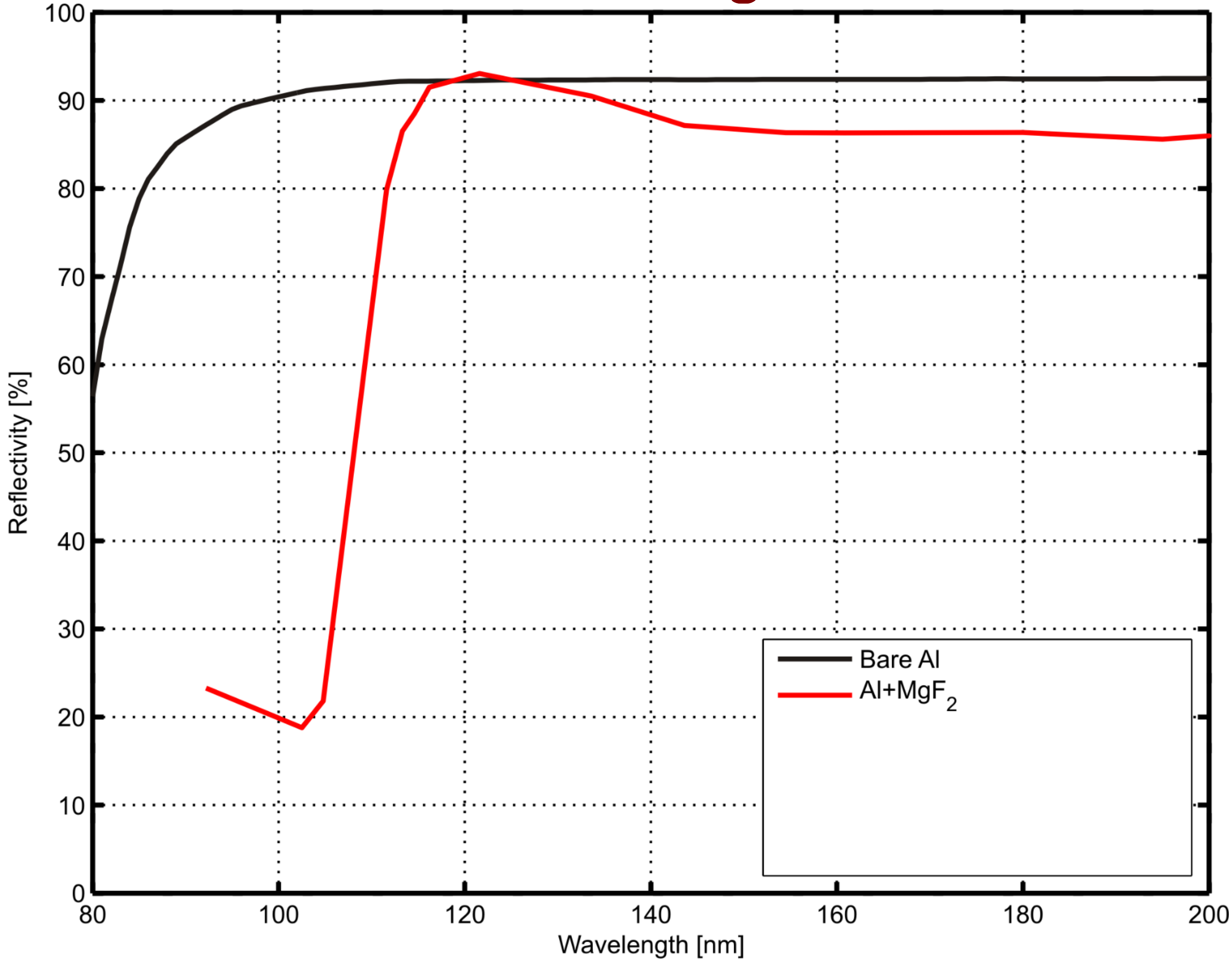
Wavelength [nm]
Bare Al

UV Coatings



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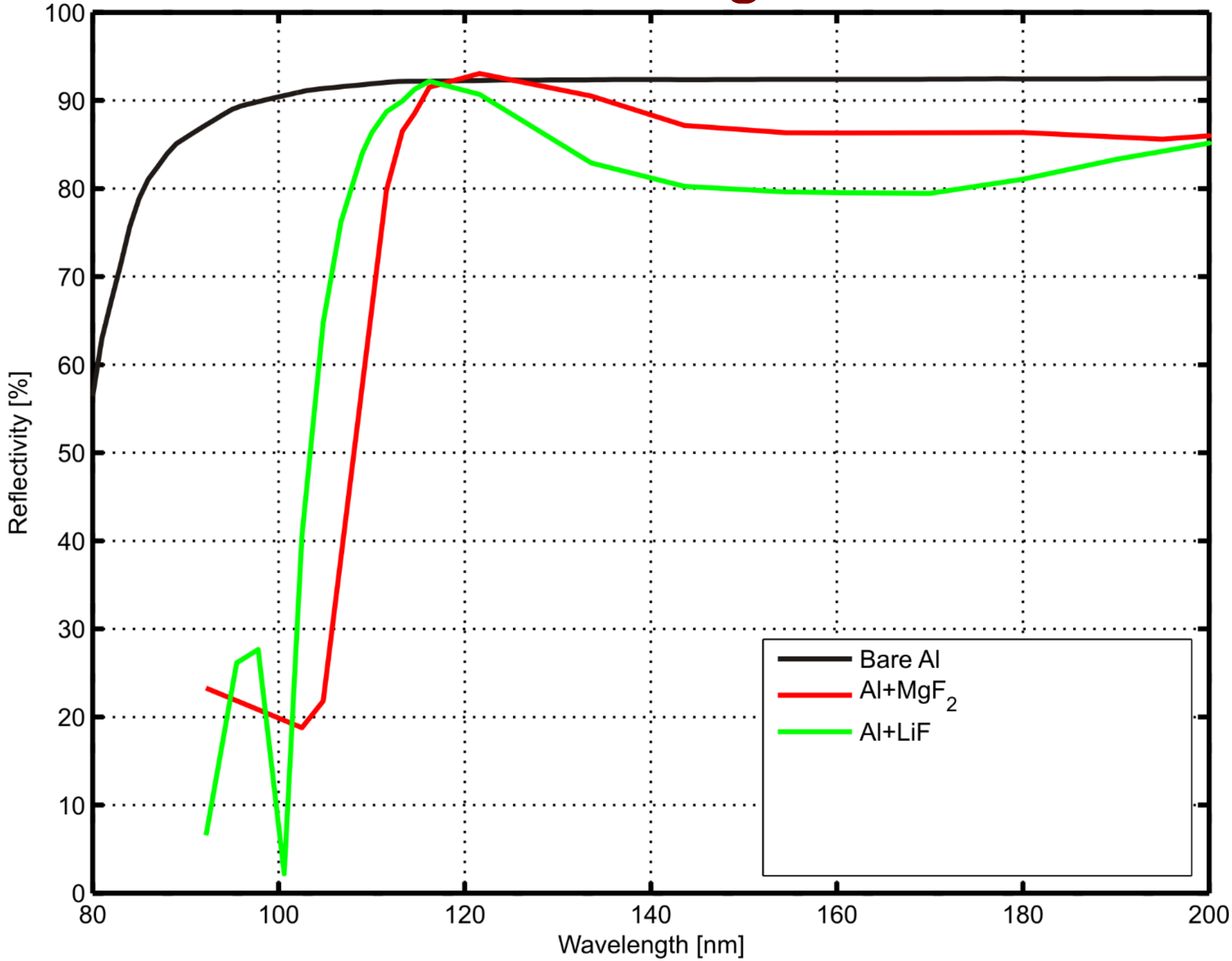

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Al+LiF

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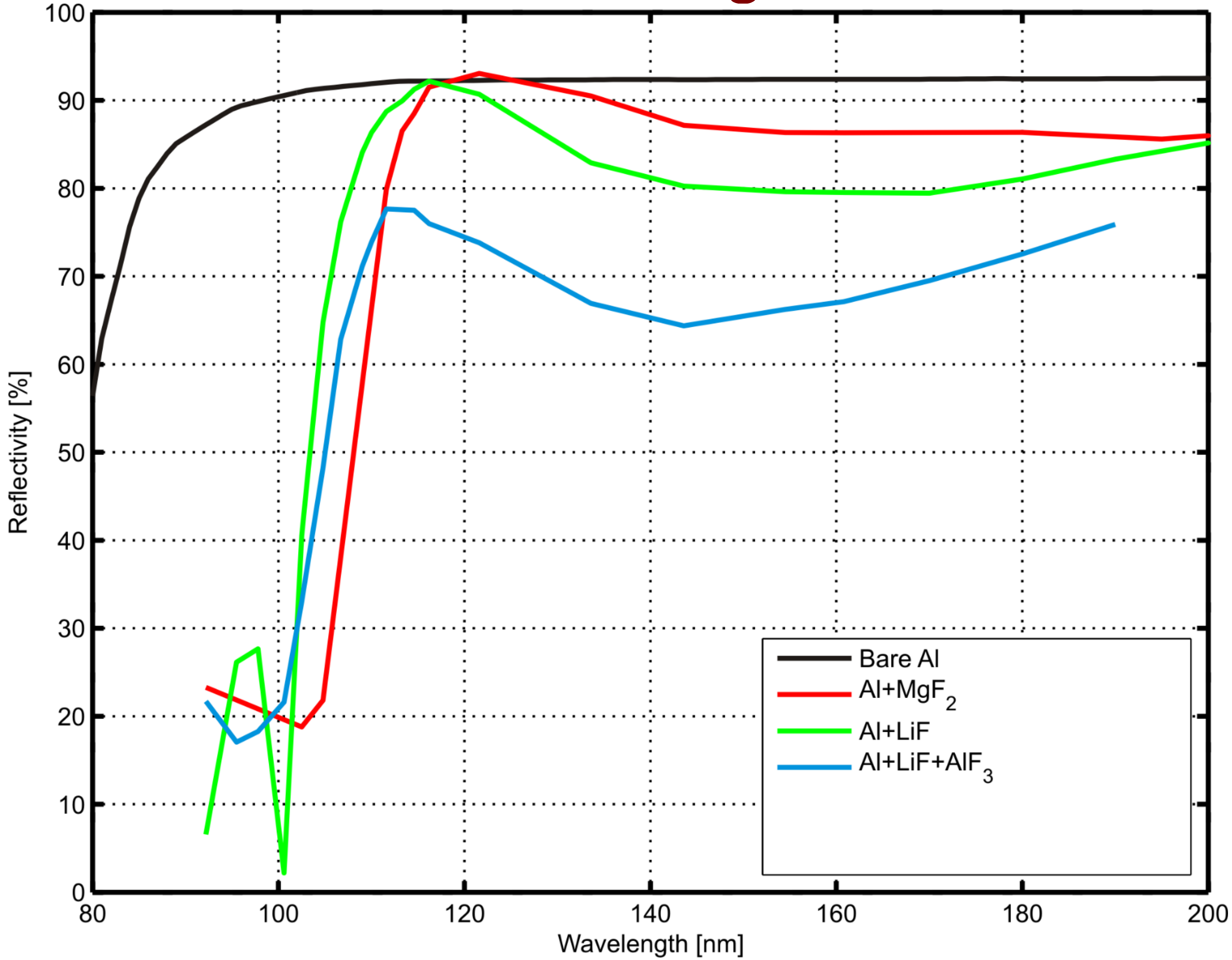

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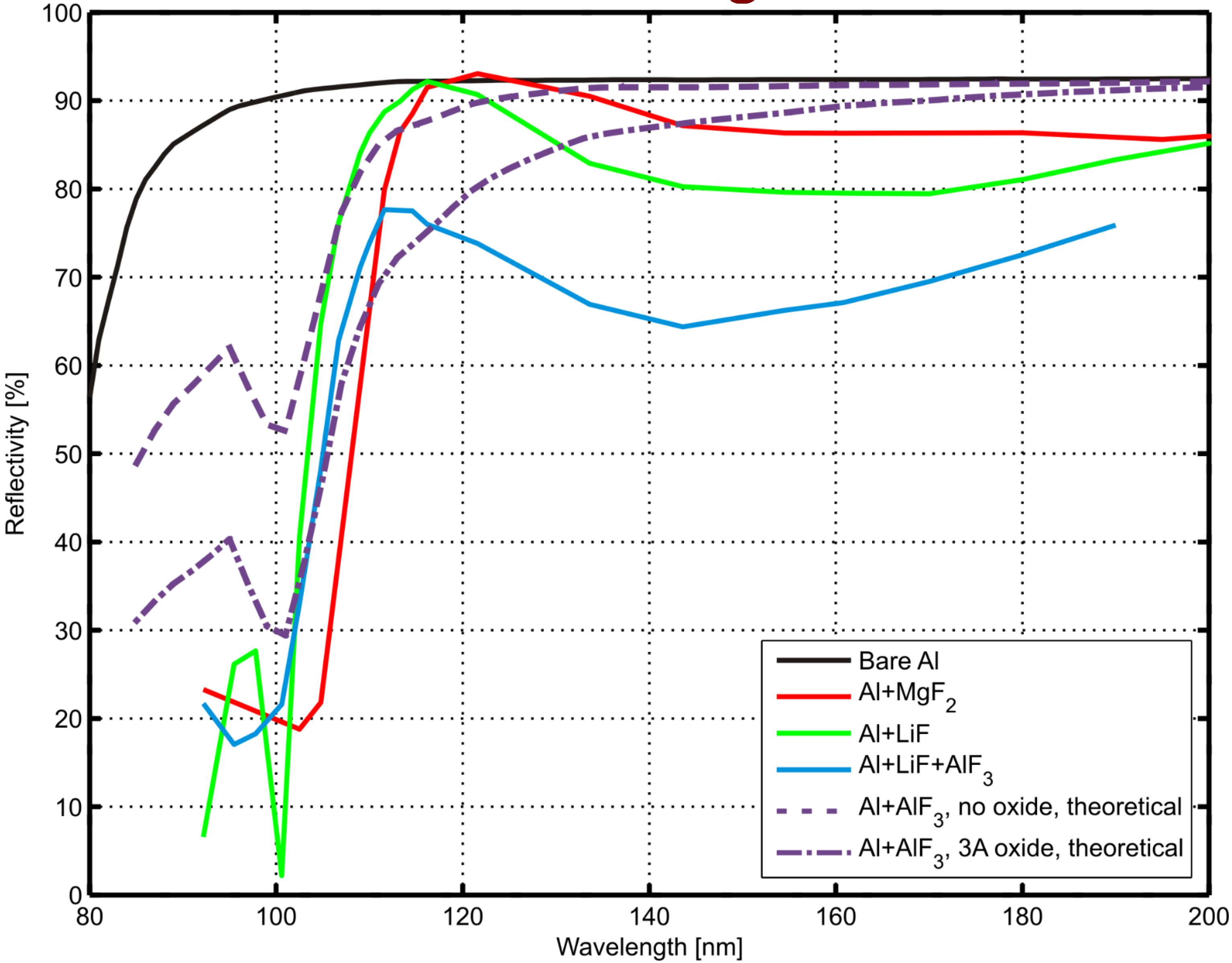

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Al+LiF+AlF3
Al+AlF3, no oxide, theoretical
Al+AlF3, 3A oxide, theoretical

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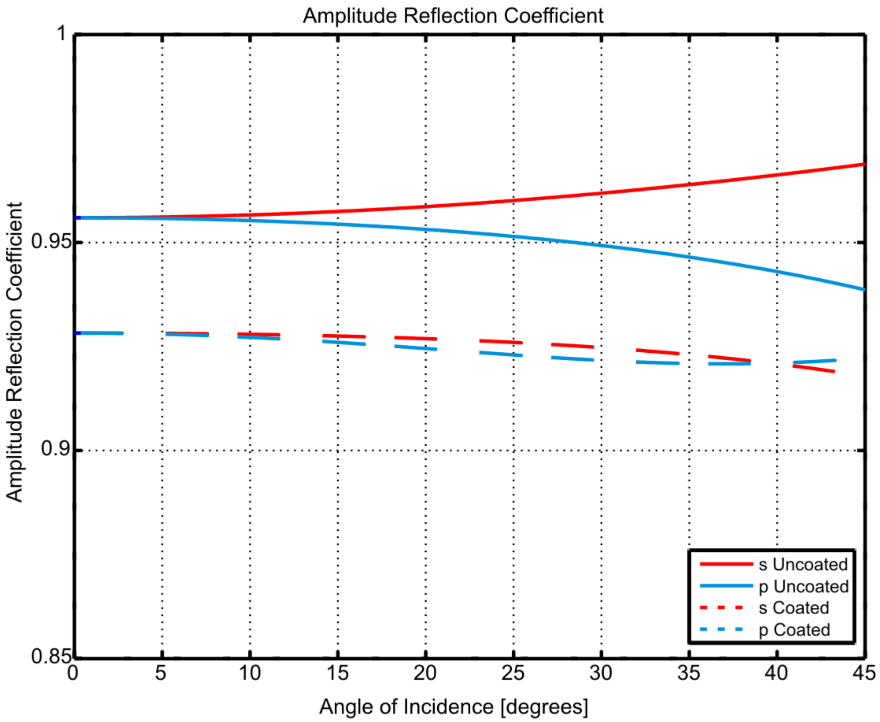
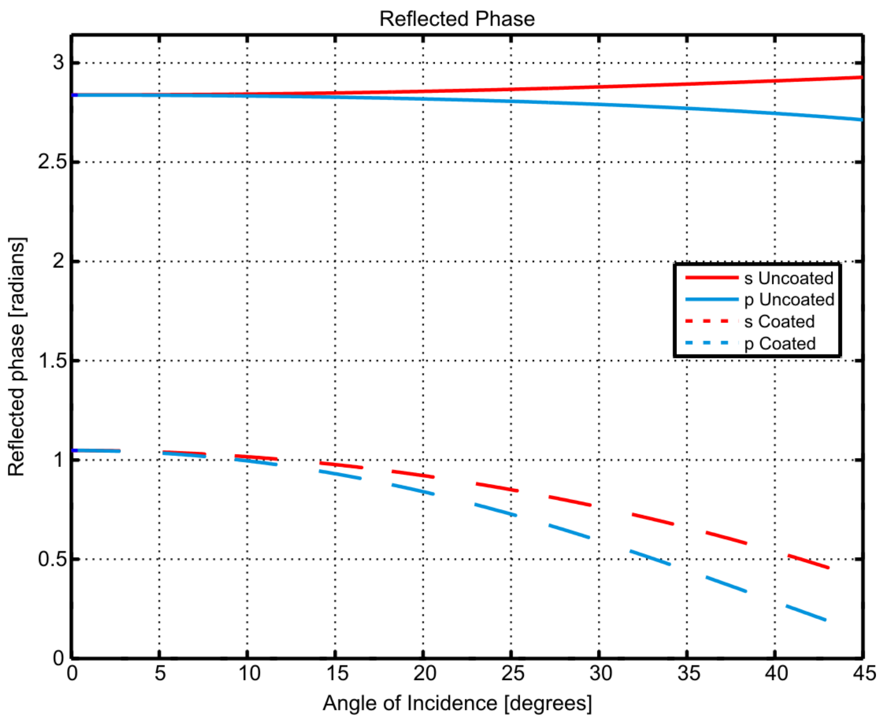
How Coatings Affect Polarization

- Terminology:
  - *Diattenuation*: when each polarization state see a different amplitude upon reflection
  - *Retardance:* when each polarization state sees a different phase upon reflection





How Coatings Affect Polarization

- There are two ***mechanisms*** of affecting the polarization-dependent amplitude and phase

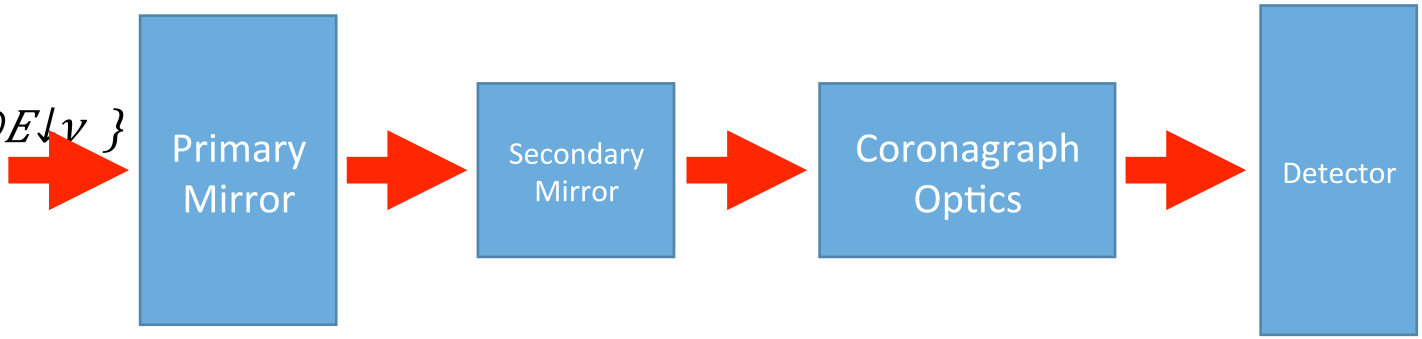
- ***Polarization Aberration:***
  - Each polarization state acquires a different amplitude and wavefront error as it traverses the system

- ***Cross-polarization Leakage:***
  - Some of each polarization state "leaks" into the orthogonal polarization state

- Net result is ***four*** incoherent (i.e. independent, uncorrelated) electric fields that must be corrected by the coronagraph

Example:

$E=\begin{Bmatrix} E_x \\ E_y \end{Bmatrix}$



$E=\{\blacksquare E_{xx}\ \&E_{yx}\ @E_{x}$

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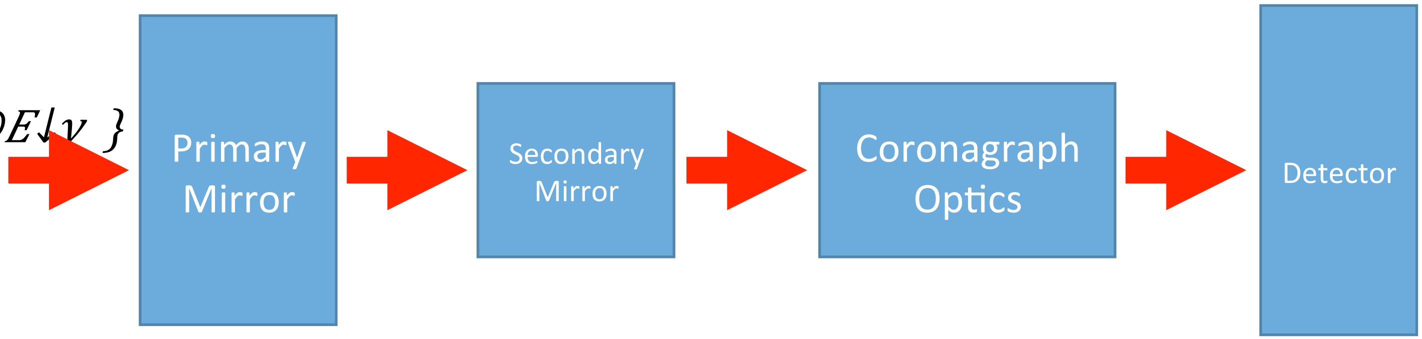

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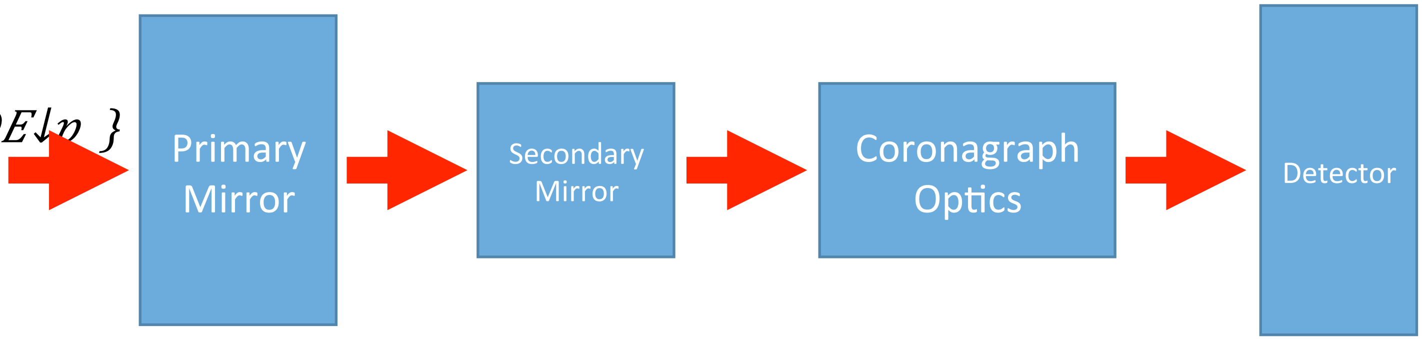
Polarization Aberration Terms

Example:

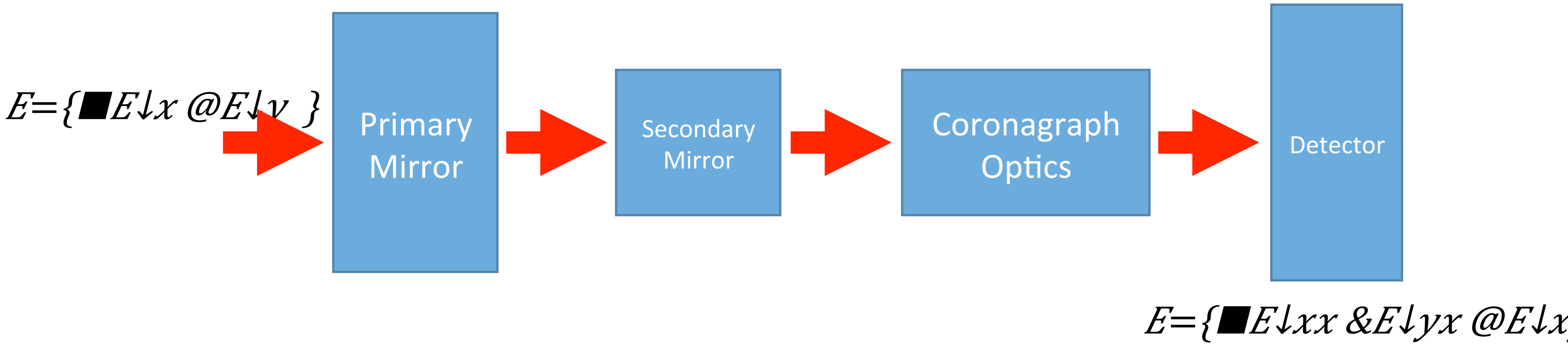
$E=\{\blacksquare E\downarrow s\ @E\downarrow p\ \}$



$E=\{\blacksquare E\downarrow xx\ \&E\downarrow yx\ @E\downarrow x$

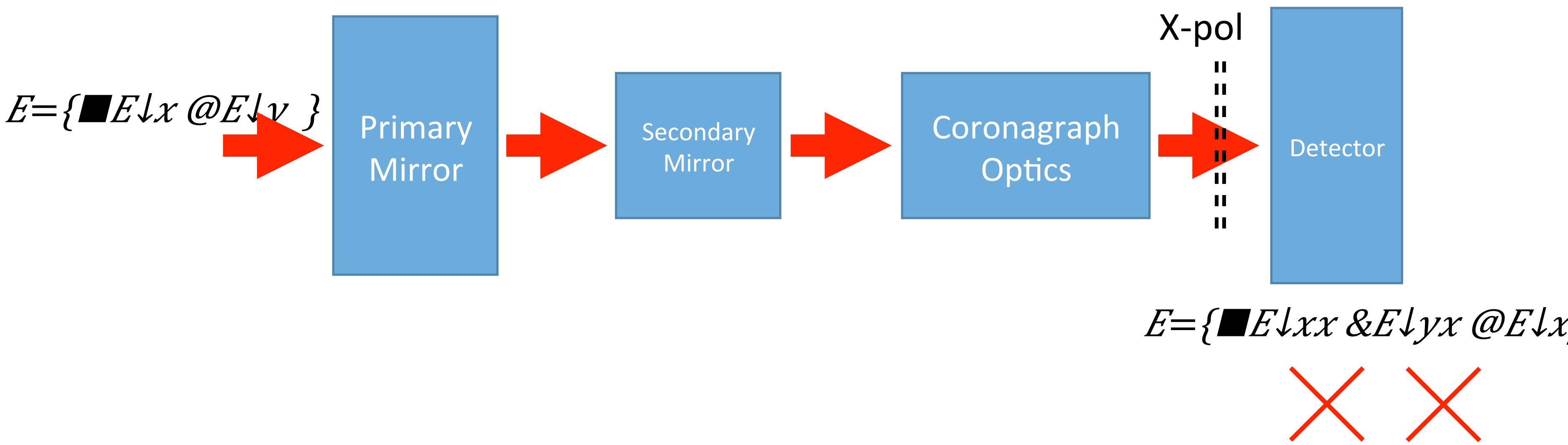
Cross-polarization Leakage Terms

Example:



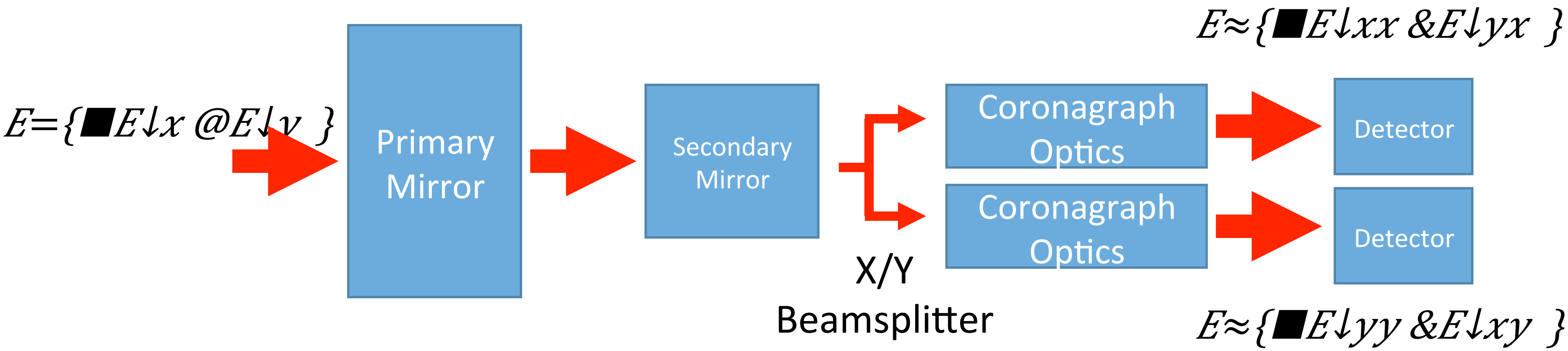
- Four incoherent (uncorrelated), aberrated fields
- If we do nothing:
  - Coronagraph senses and corrects the average electric field
  - Uncorrected portion contributes to contrast leakage

Potential Solution #1:



- Filter polarization at detector plane
- Image is constructed of only “x” polarization components
- Again, coronagraph senses and corrects the average of the remaining terms
- $E_{xx} >> E_{yx}$ so we get good, but imperfect correction
- But you lose 50% of the light at the detector

Potential Solution #2:



- Split polarizations before entering separate coronagraphs
- Still sensing average of primary and cross-polarization fields, so correction is good, but imperfect
- Retain 100% of the light
- Requires 2x coronagraphs (2x optics, 2x detectors, 2x DMs)

Other Mitigation Strategies

- Limit angles-of-incidence (AOI):
  - Slower primary and secondary mirror F/#'s
  - Avoid flat-fold mirrors at high AOI
    - Can be used in "crossed-pairs" to cancel each other out
  - Creates "long" optical systems which makes packaging and stability difficult

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- Polarization compensating components:
  - Investigate active or passive devices that may be able to compensate polarization aberrations
    - Liquid crystals, nonlinear devices, etc.

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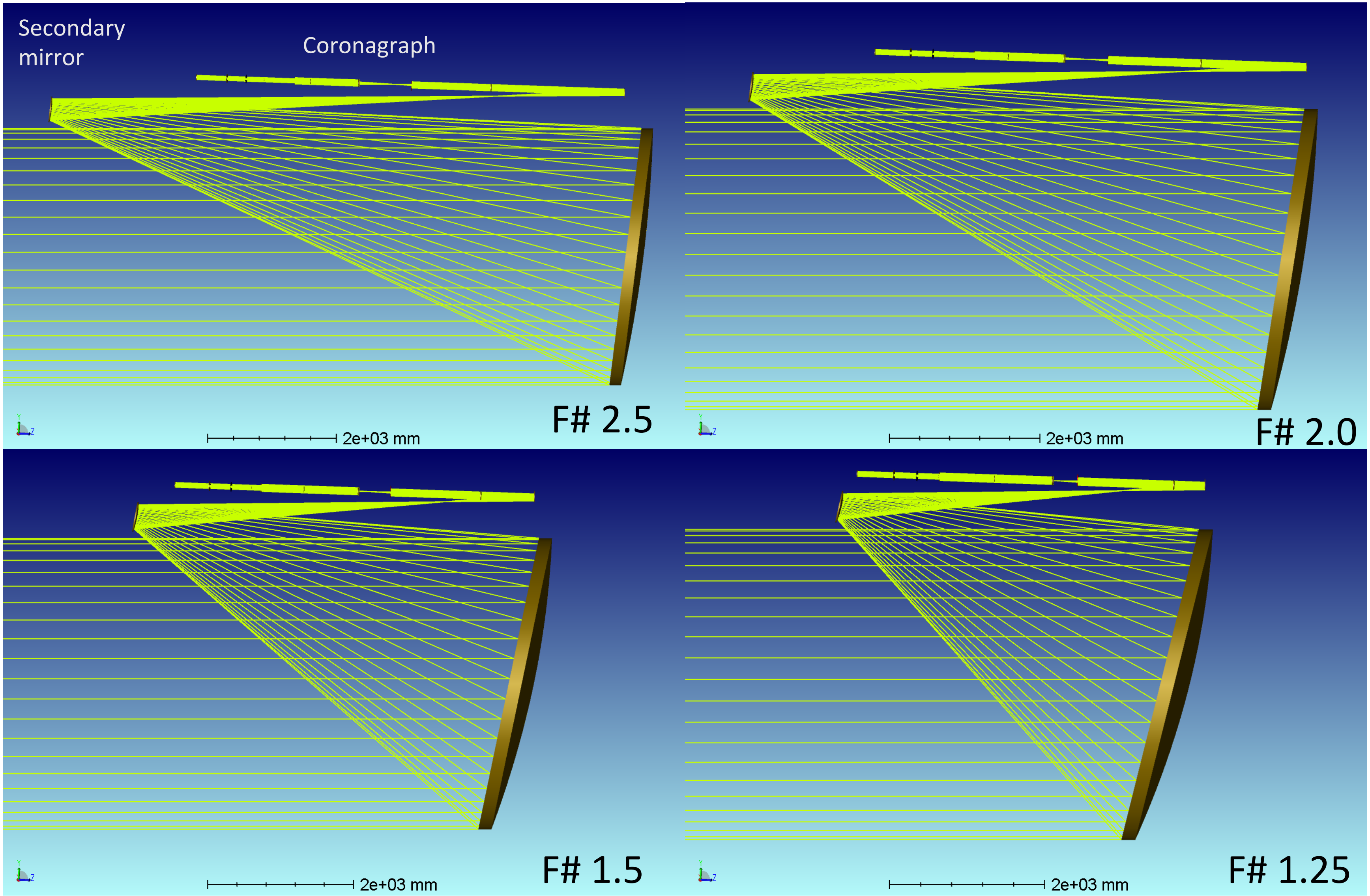
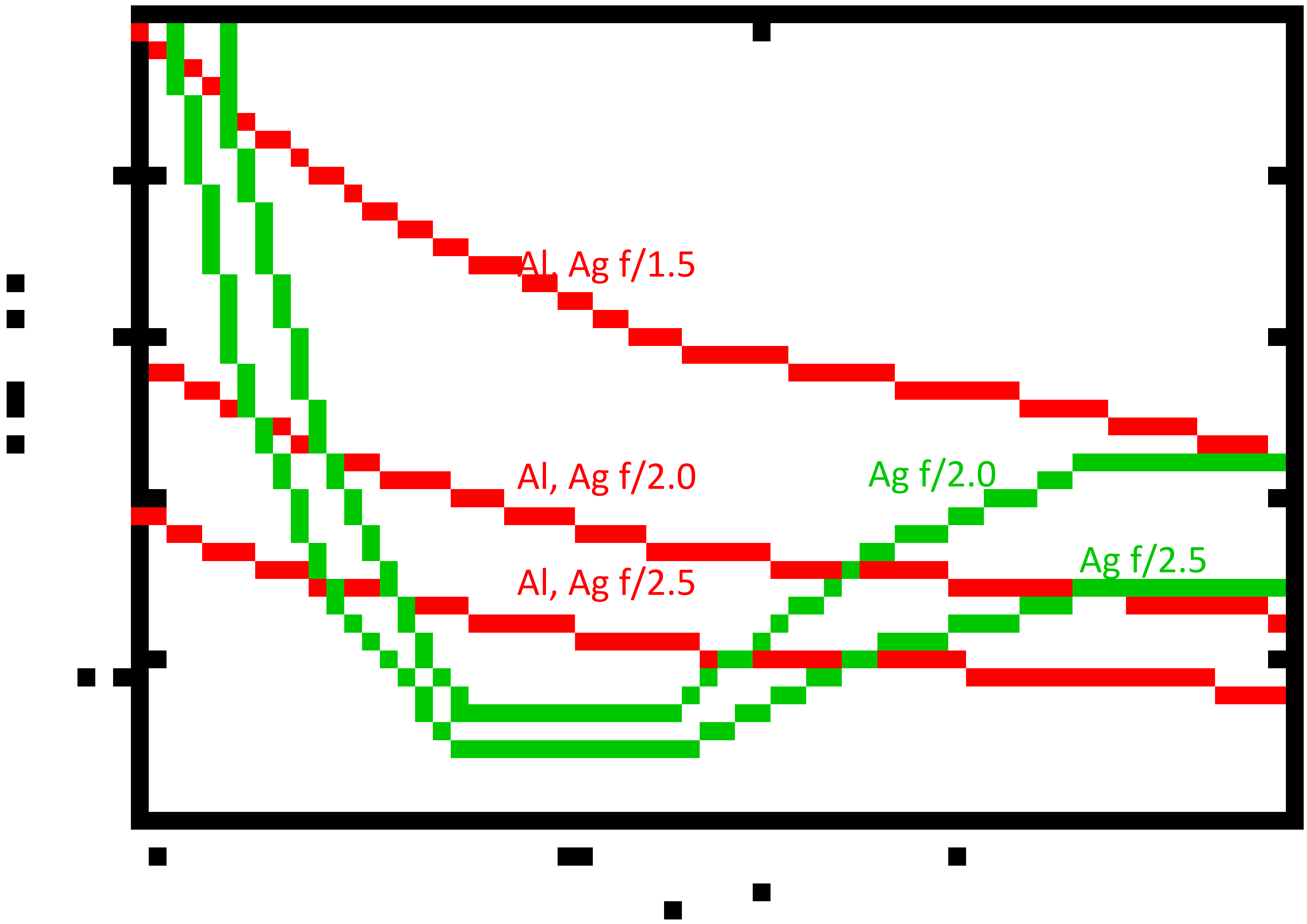
HabEx Polarization Study

- Design based on Exo-C Telescope resized from 1.4 m to 4.0 m diameter
- Telescope is an off-axis, unobscured Ritchey-Chretien design
- Produced a family of designs with primary mirror F#s of 2.5, 2.0, 1.5, 1.25
- For analysis, polarization wavefront analyzed from primary mirror to DM1
- Two scenarios:
  - Coatings on PM, SM, TM are aluminum, with silver on rest of optics, OR
  - All mirrors are silver

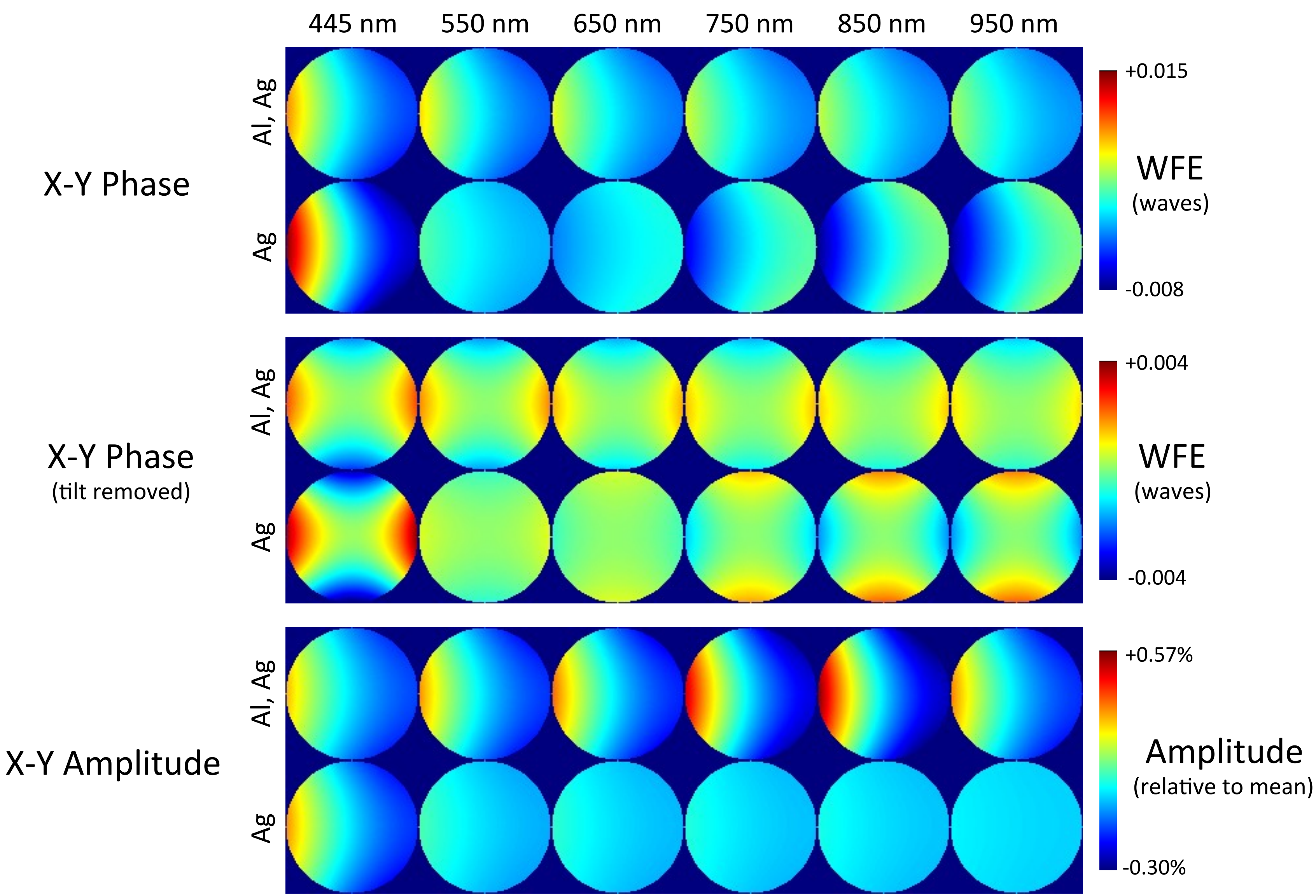
Four designs, Primary F#s 2.5, 2.0, 1.5 and 1.25



X-Y RMS WFE

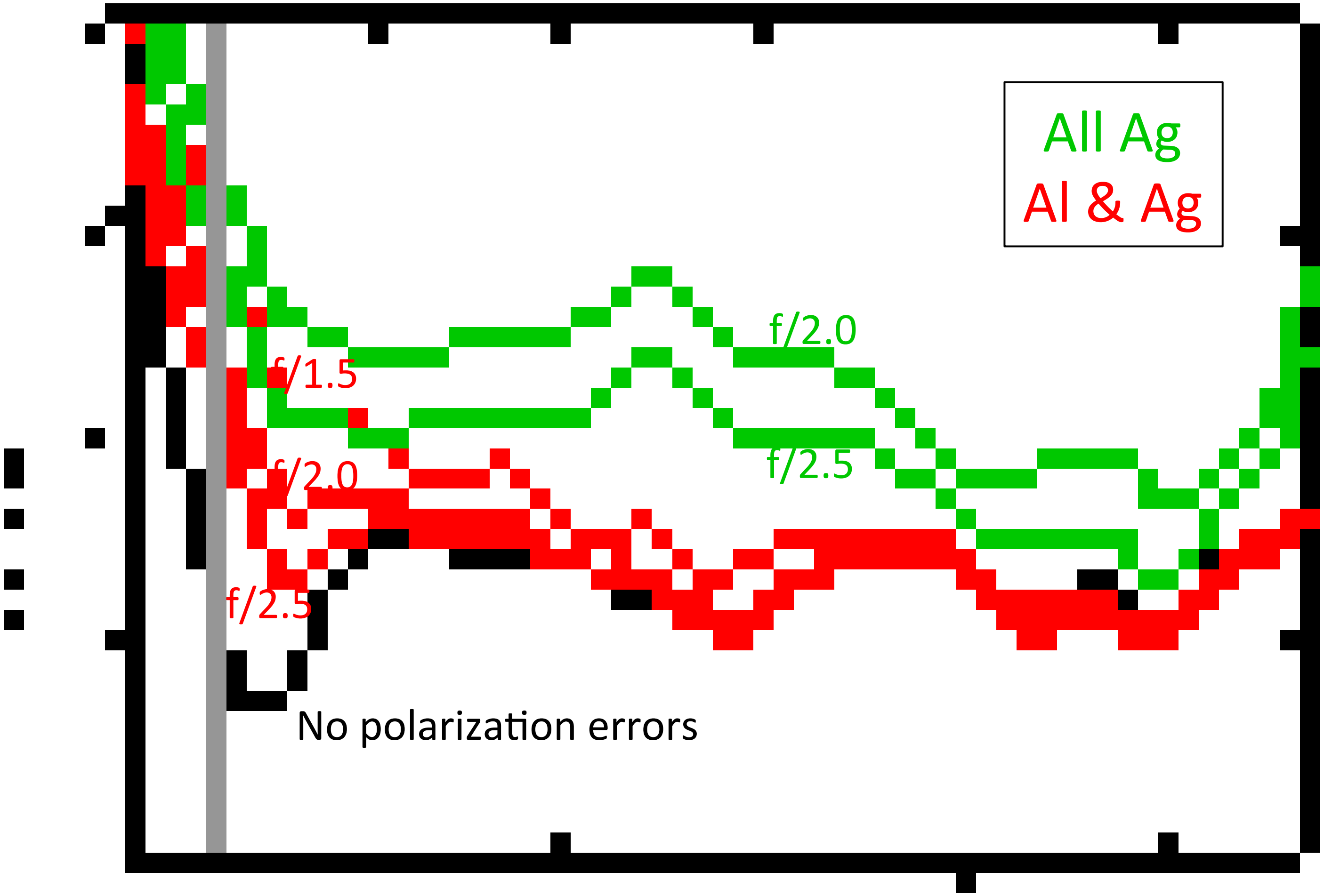


HabEx: X-Y Polarization Wavefront Differences, f/2.5



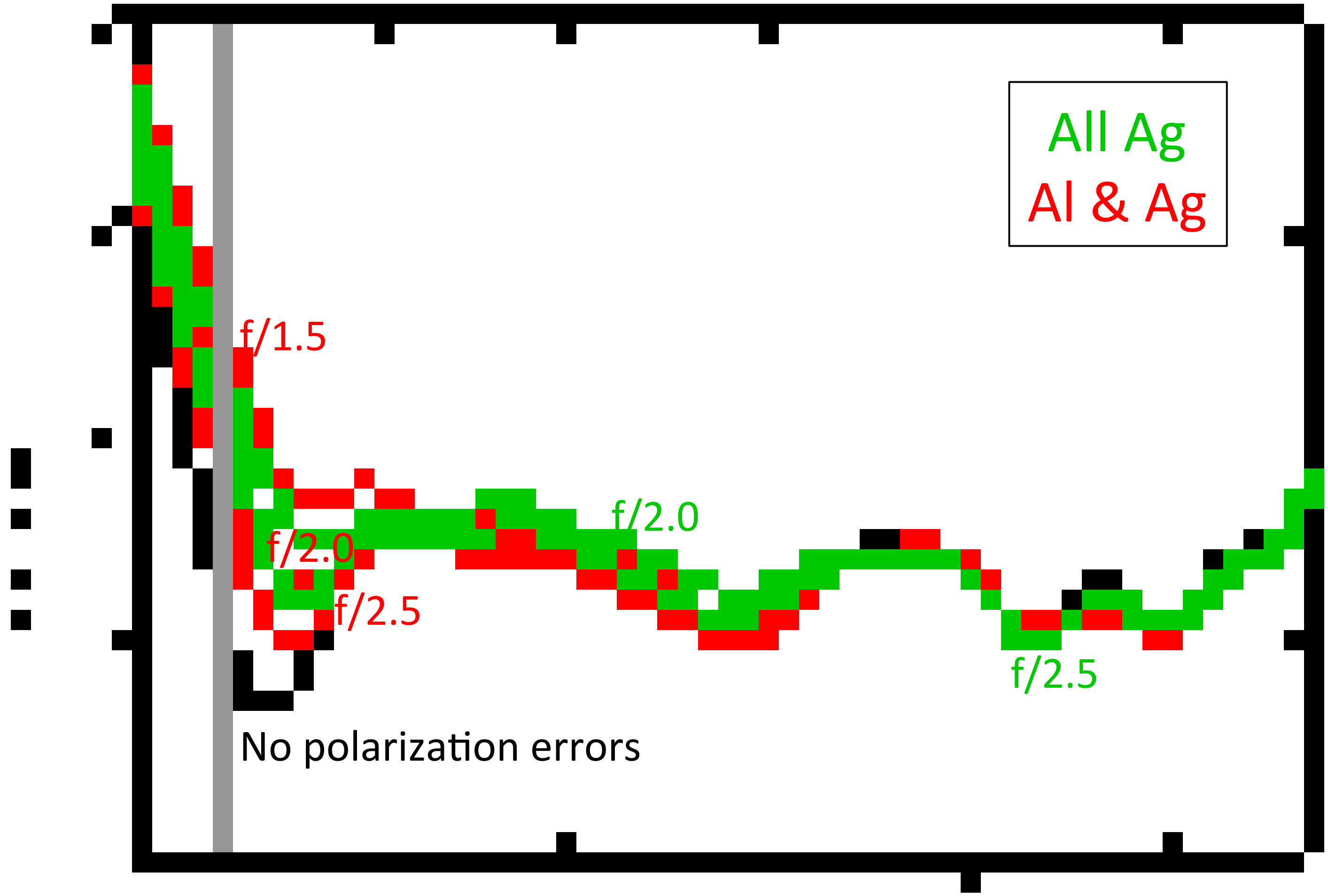
Tilt & astigmatism are the main polarization aberrations

HLC: Post-EFC Contrast: 400-490 nm
All polarizations



HLC: Post-EFC Contrast: 720-880 nm

All polarizations



One Line Summary (courtesy J. Krist):

"Use overcoated Aluminum on the 1st three optics."

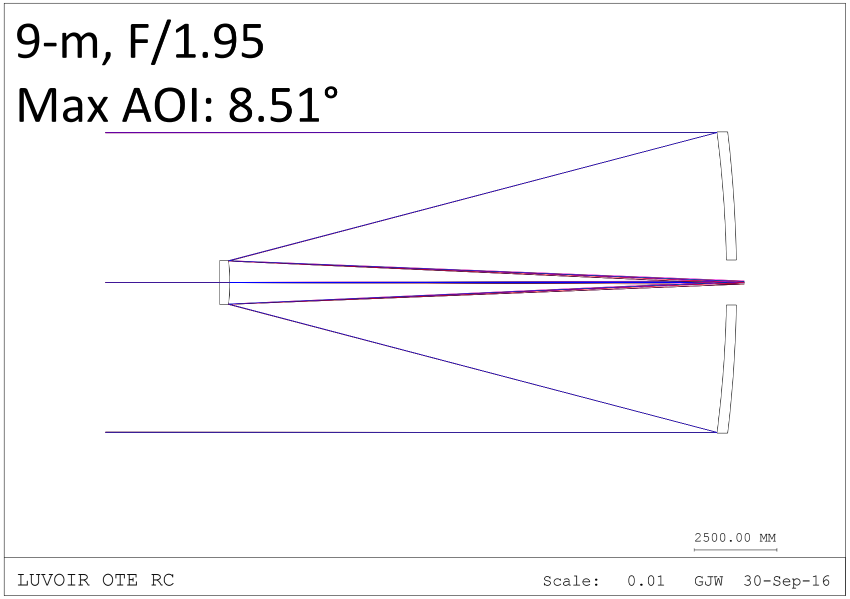
LUVOIR Polarization Study

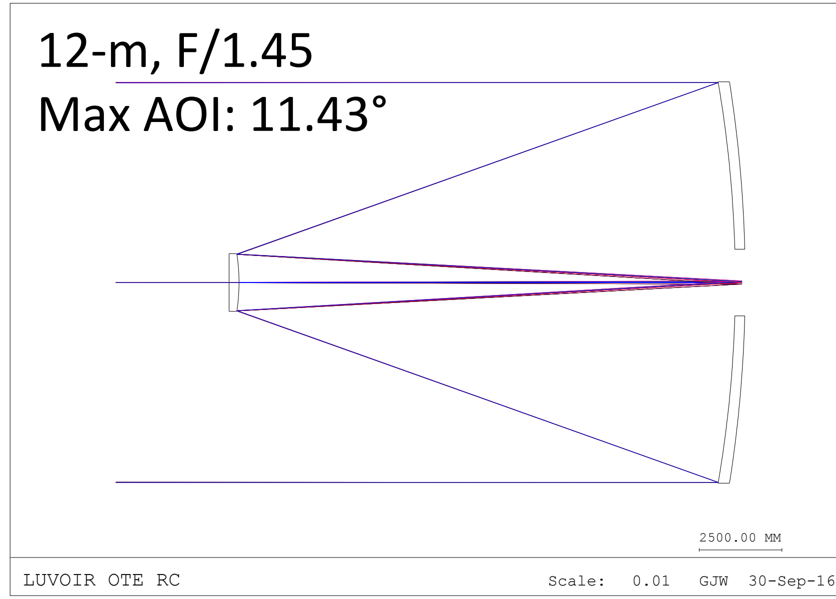
- Four Ritchey-Chretien telescope designs generated:
  - 9m, 12m, 16m on-axis
  - 9m off-axis

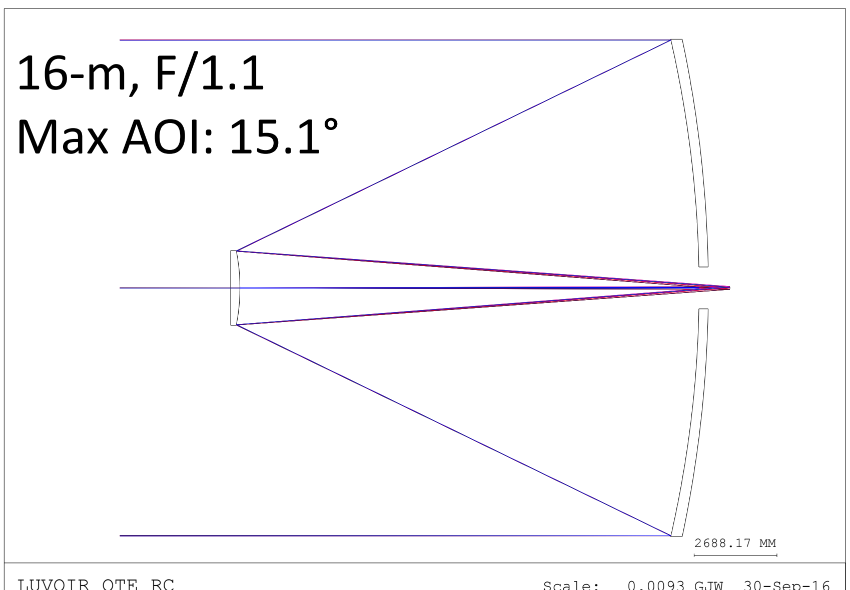
- All designs have:
  - 3x3 arcmin diffraction-limited field-of-view
  - 15 meter Primary-to-Secondary Mirror separation
  - Same focal length and hence same plate scale (pixel size on sky)
  - Aluminum-coated mirrors

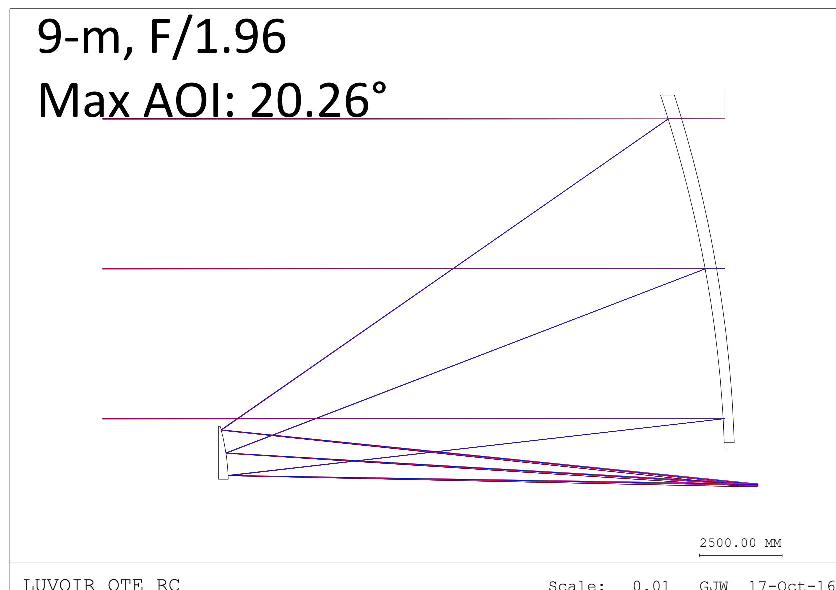
- Primary mirror F/# varies with design:
  - F/1.1 for 16-m
  - F/1.45 for 12-m
  - F/1.95 for 9-m on-axis
  - F/1.96 for 9-m off-axis

LUVOIR Designs









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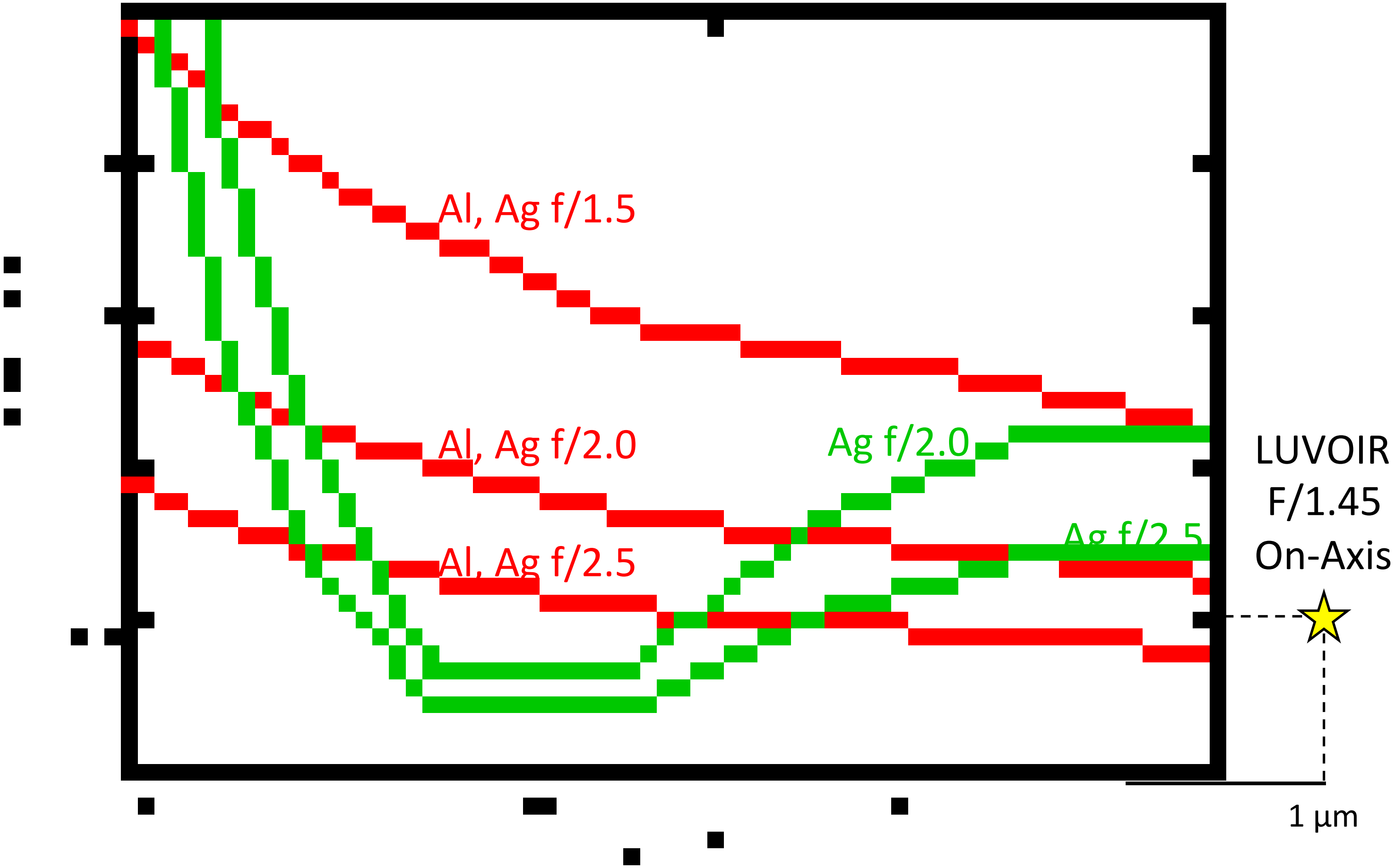

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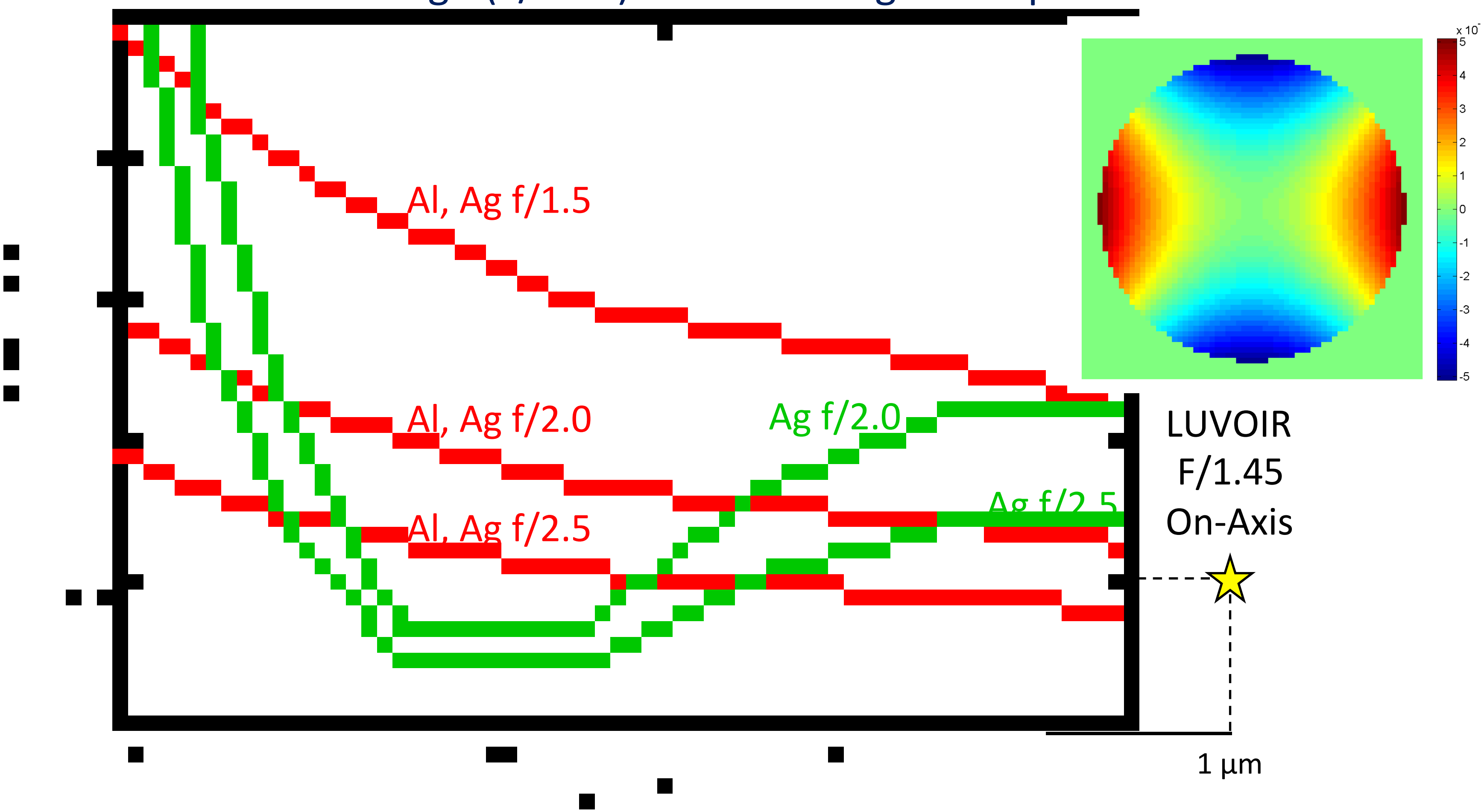

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- If different coronagraph channels will be used to process each polarization orientation separately, need to understand impact of cross-polarization leakage

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    - Performance below 110 nm depends on prescription and deposition processes
- Both LUVOIR & HabEx are pursuing parametric studies to understand trades with respect to telescope aperture and design
- HabEx study shows aluminum coating appears to be better than, or approximately equivalent to, silver coating with respect to polarization