The WFIRST Coronagraph Instrument Optical Design Update

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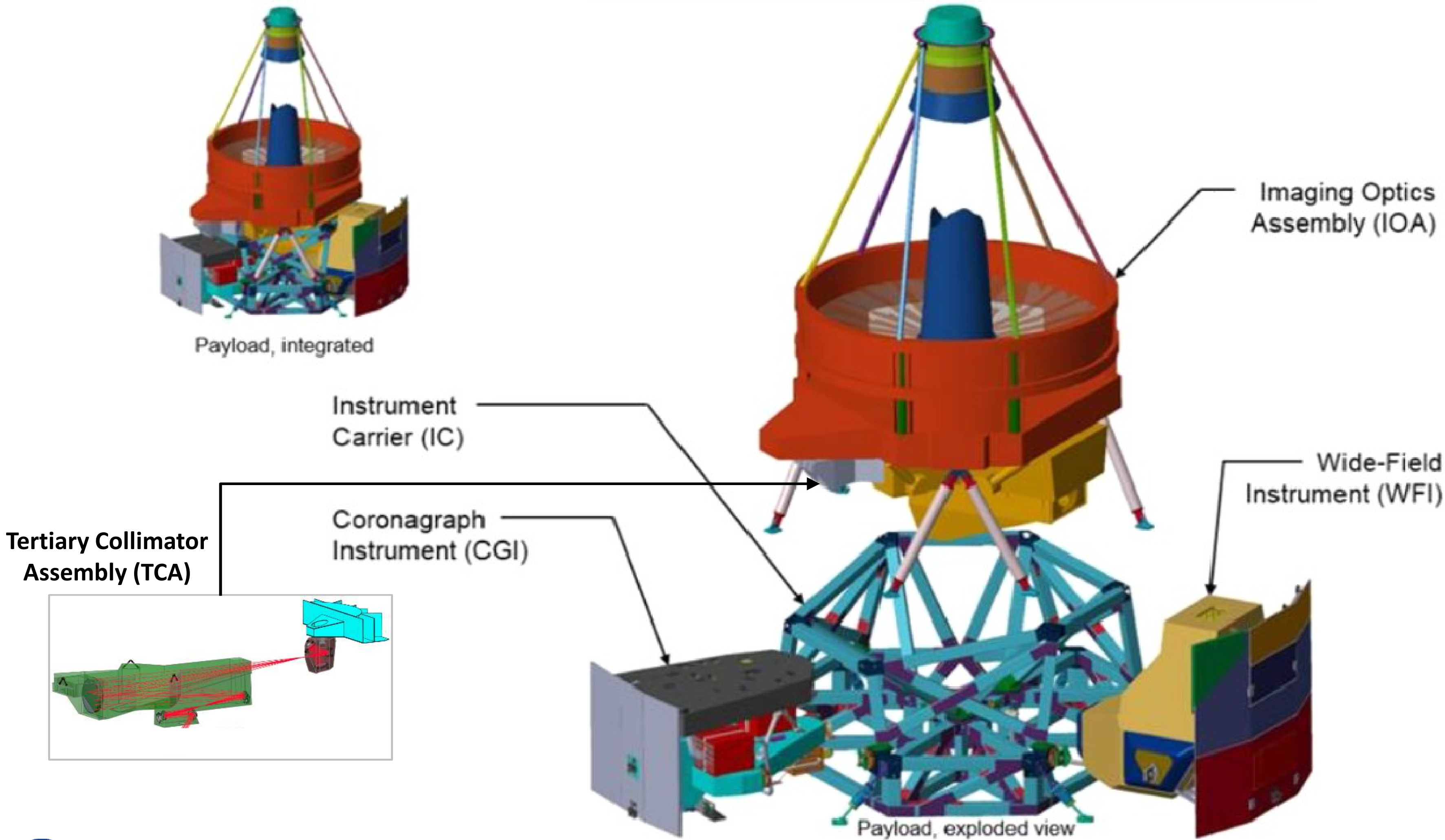
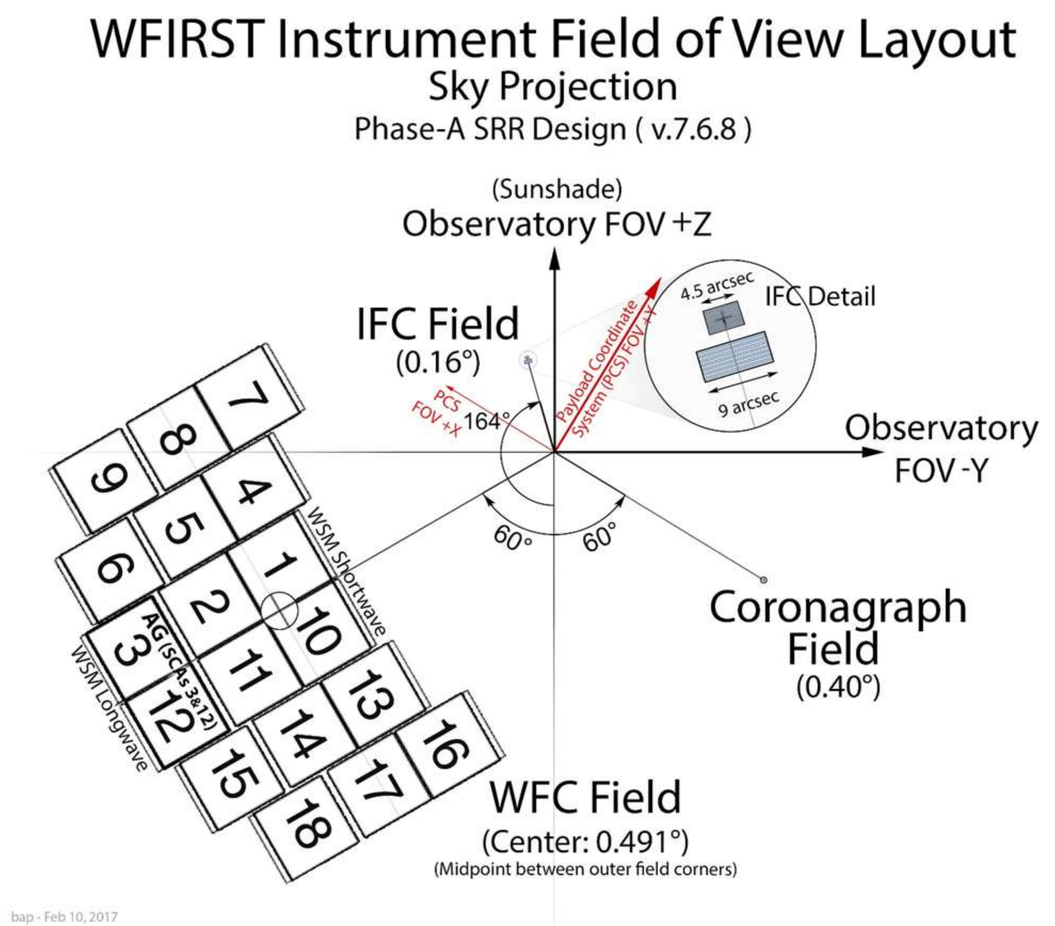
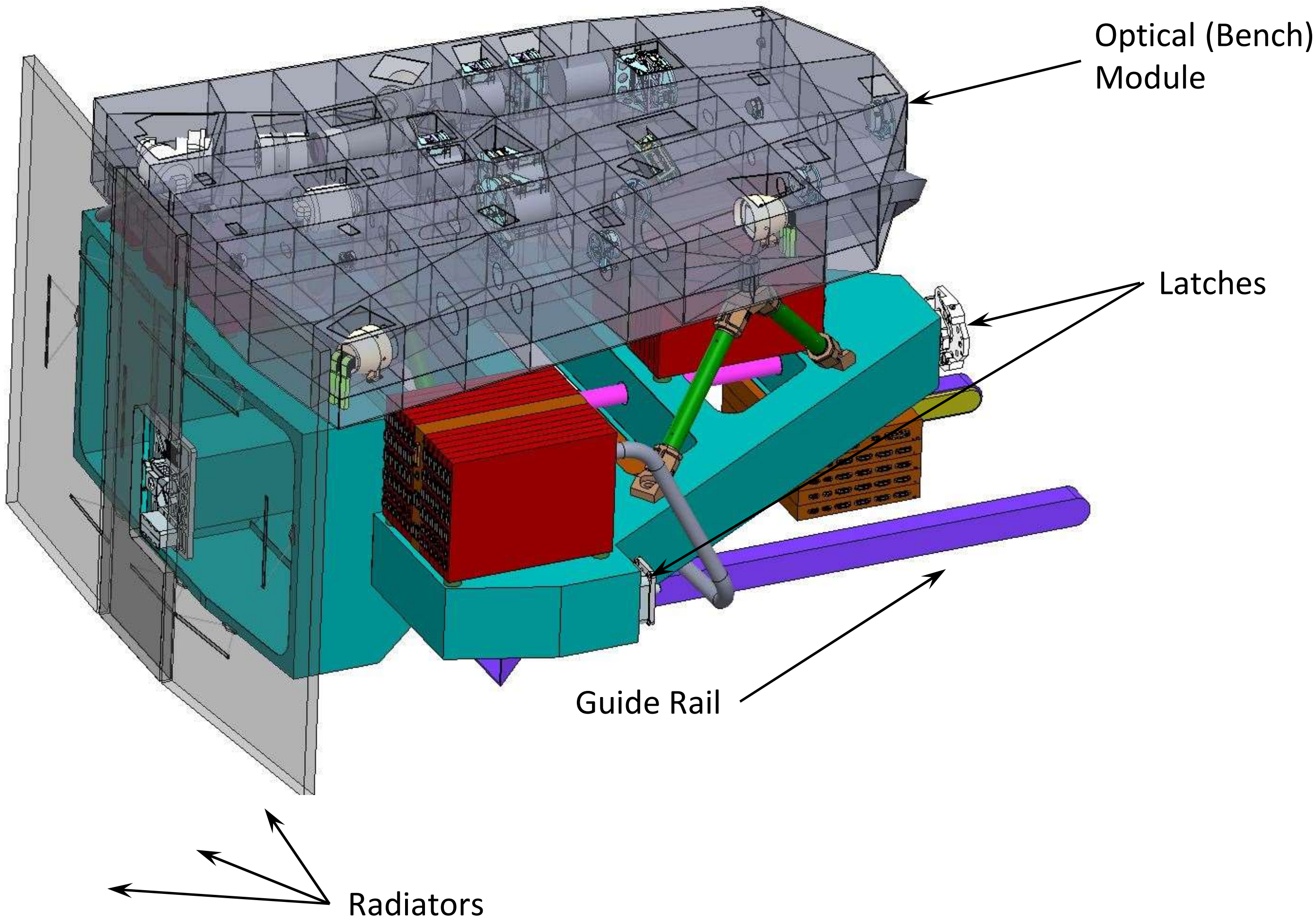
WFIRST Payload



WFIRST Instrument Field of View



Coronagraph Instrument (CGI)



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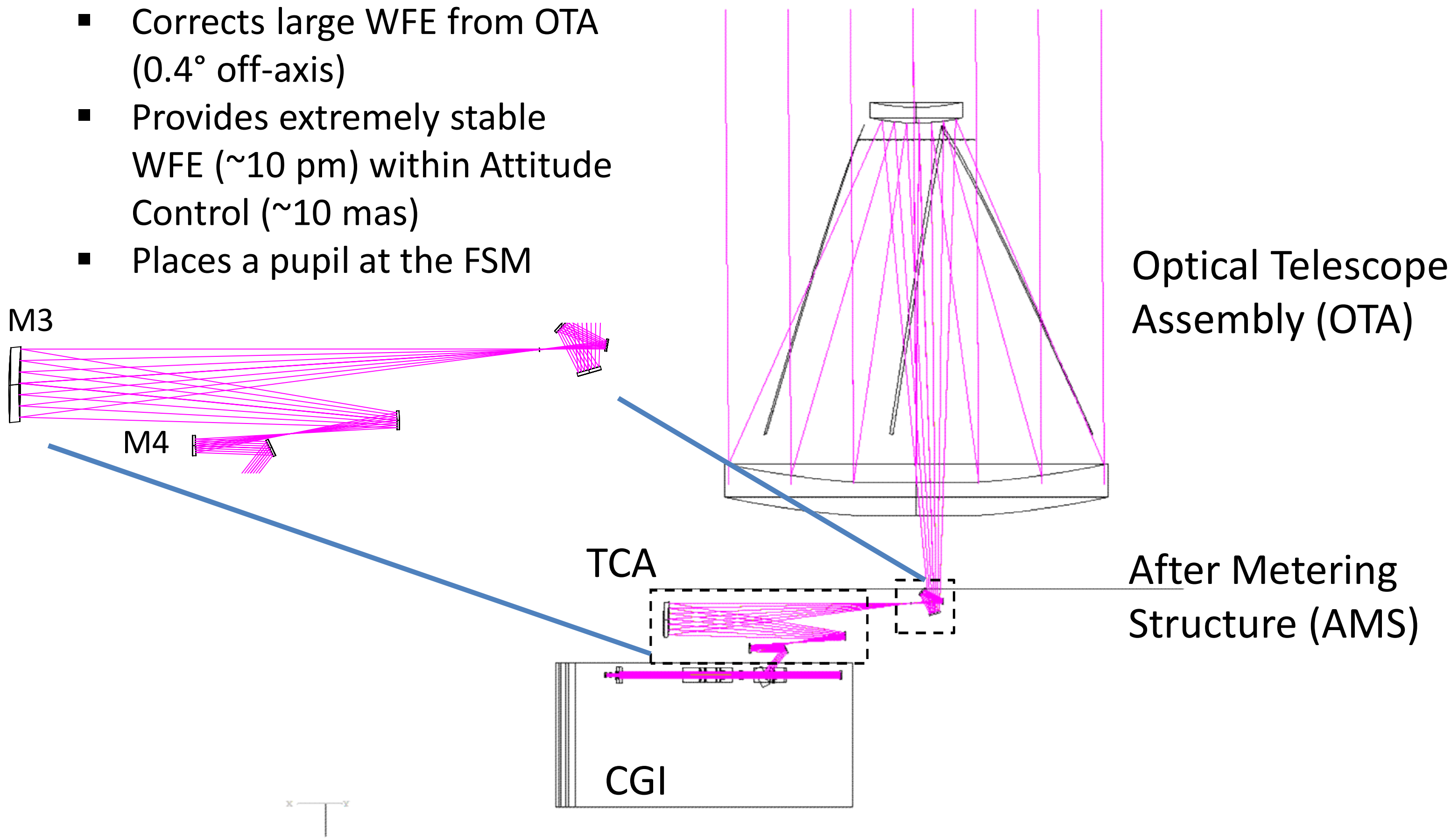
Tertiary Collimator Assembly (TCA)

Tertiary Collimator Assembly - TCA

- Corrects large WFE from OTA (0.4° off-axis)
- Provides extremely stable WFE (~10 pm) within Attitude Control (~10 mas)
- Places a pupil at the FSM



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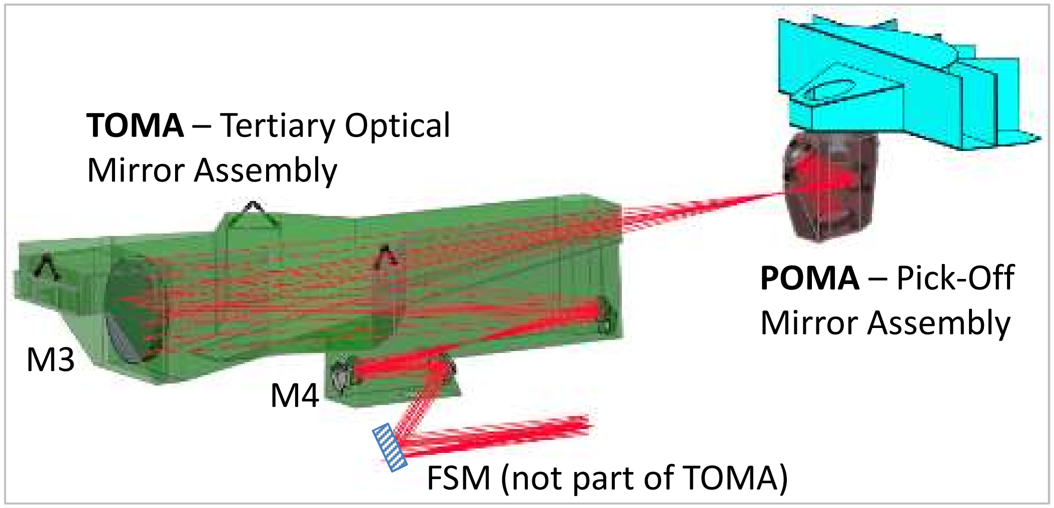
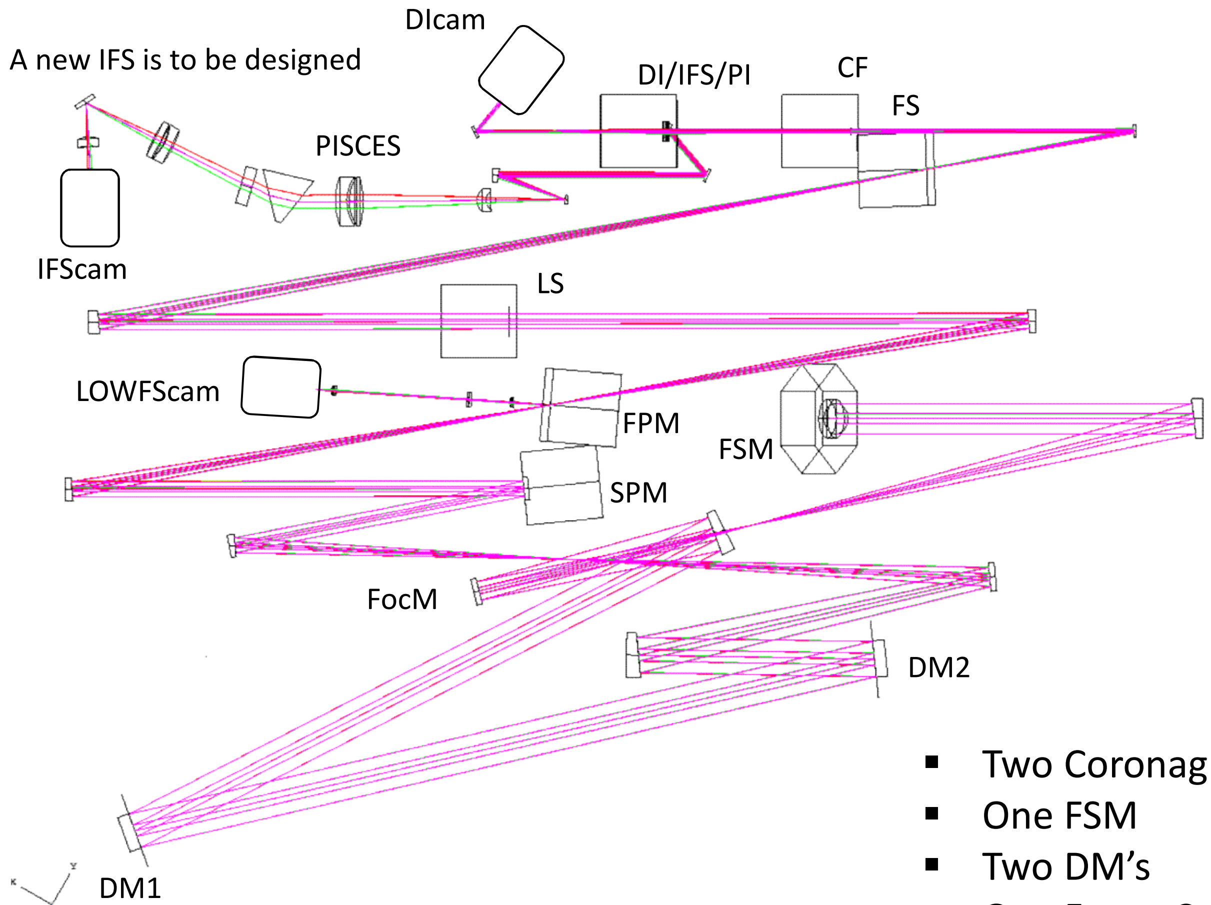
TCA Updates



- TCA splits into two assemblies, POMA and TOMA
- TOMA and POMA are attached to After Metering Structure (AMS) of the Optical Telescope Assembly (OTA)
- Coronagraph pick-off mirrors increases from two to three (as a result of Wide Field Instrument's M3/F1 trade)
- M3 and M4 are re-optimized to simple conic surfaces
- Exit pupil is 40 mm (was 46 mm), more margin for FSM optic
- Exit pupil extends to FSM (was 200 mm short of it)

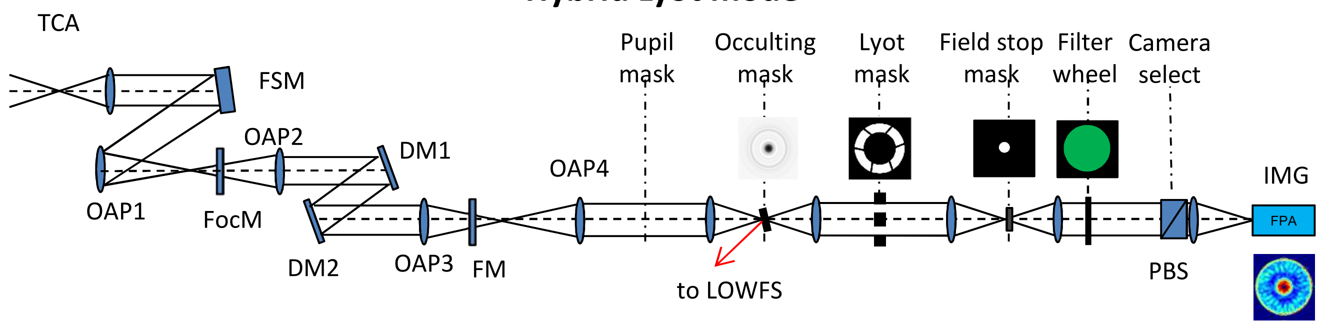
CGI Optical Layout



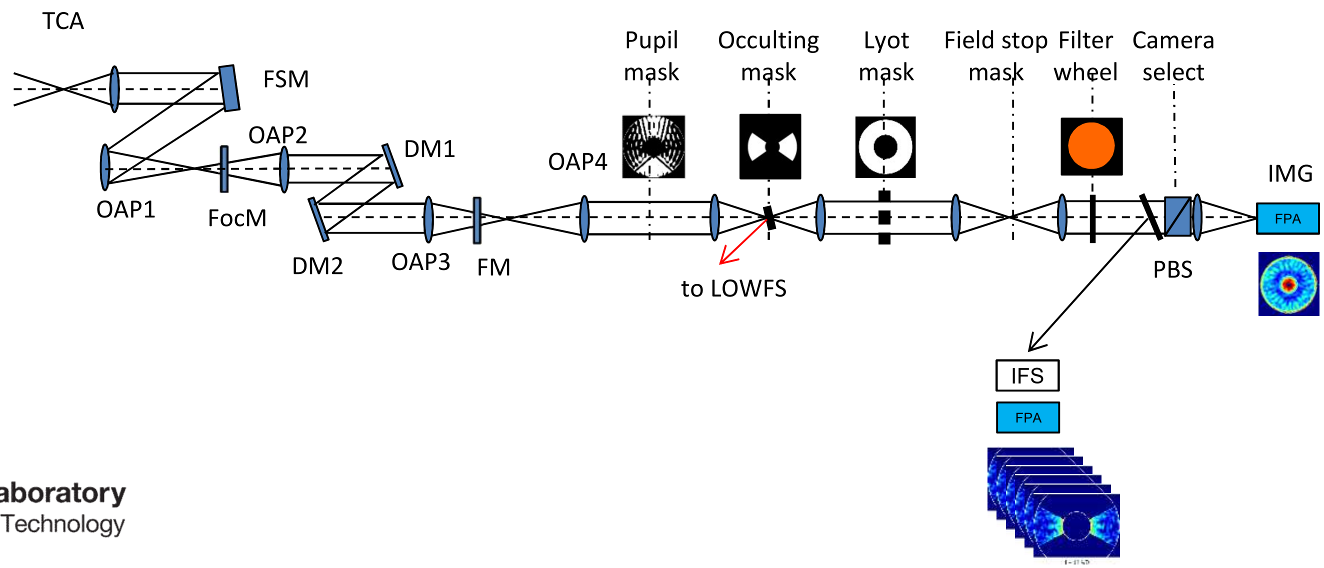
- Two Coronagraph Architectures
- One FSM
- Two DM's
- One Focus Correction Mirror
- Six wheel mechanisms
- Three CCD cameras

Operation Modes

Hybrid Lyot mode



Shaped Pupil mode

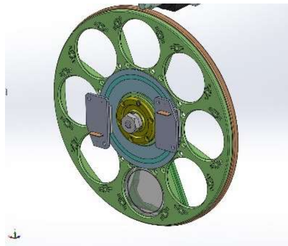


CGI Updates

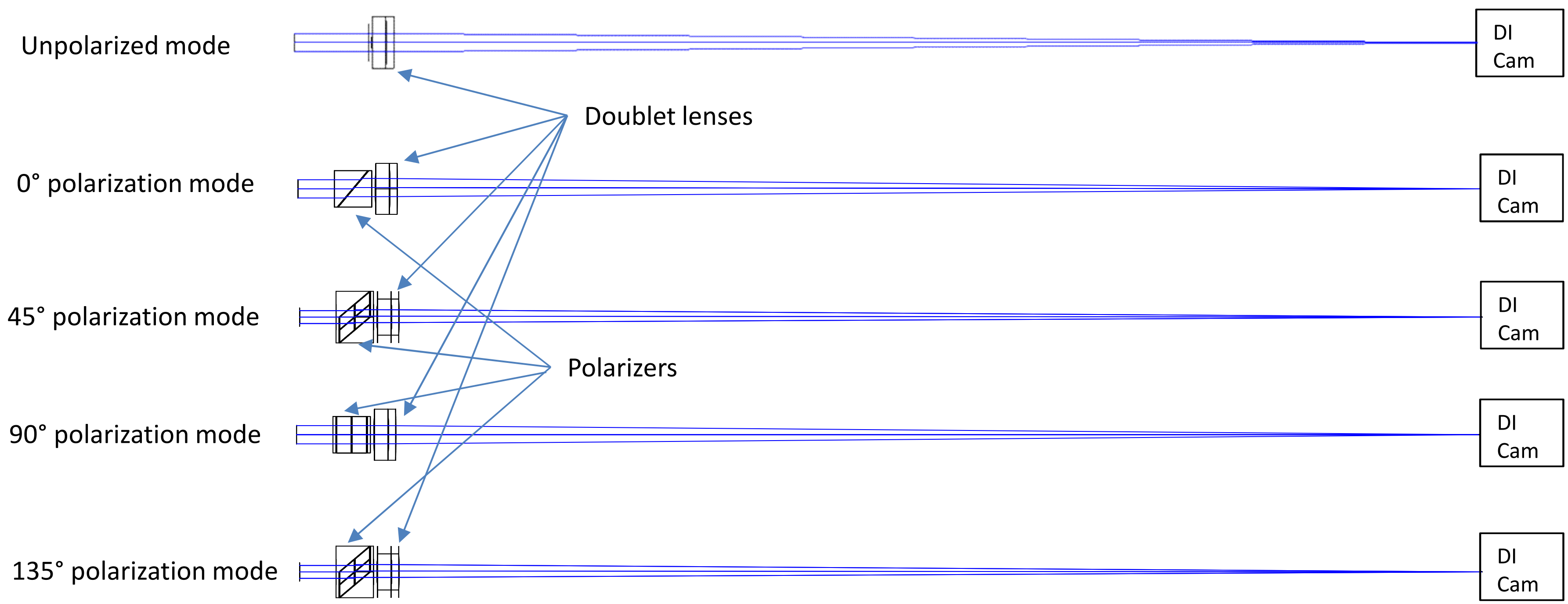
- CGI starts from FSM
- Eliminates several fold mirrors, only one remains
- Adds un-polarized mode in Direct Imaging Channel
- Added 45° and 135° polarized imaging modes
- PISCES is serving as a place holder for IFS
  - An IFS is being designed in Phase A according to L2/L3 Requirements

Direct Imaging Modes

Lenses and polarizer/lens subassemblies on Camera Select wheel (DI/IFS/PI)



- Un-polarized image
- Linearly polarized images (0°, 45°, 90°, 135°)
- Pupil image (not shown below)
- Four defocused images (not shown below)



CGI Performance Parameters

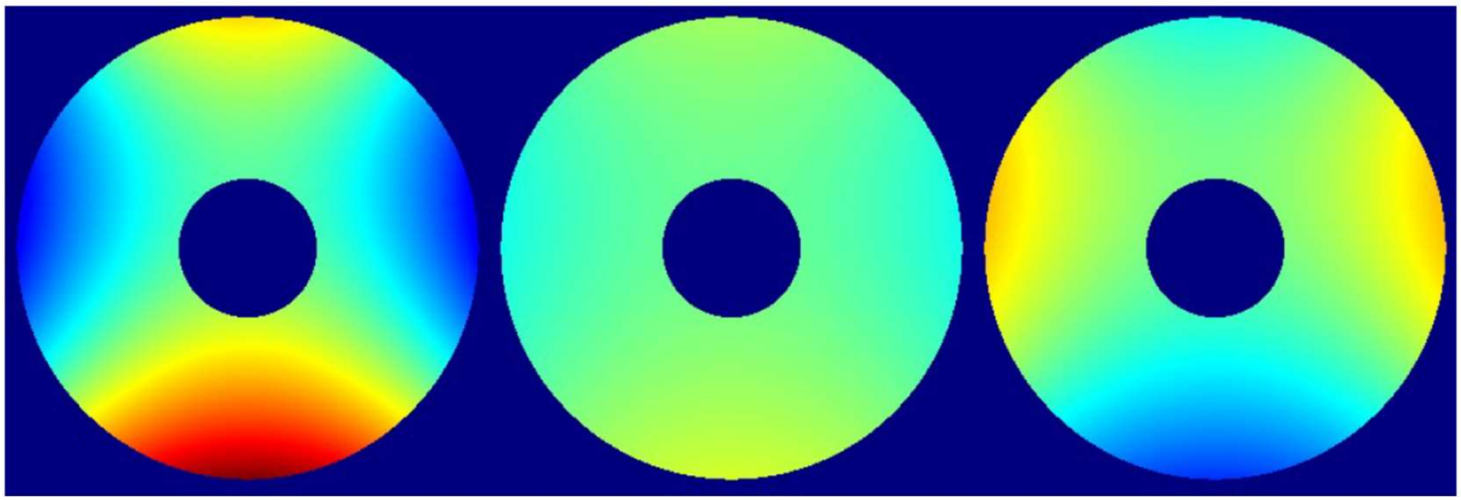
Design Specifications		Value	Unit
WFE (on CGI axis)	After SM	6380	nm (rms)
	After M4	7	
	At FPM	7	
ΔWFE (100 mas off CGI axis)	After M4	30	pm (rms)
Imaging pixel plate scale		0.02	arcsec
Imaging FOV (full)	without masks	10	arcsec

Differential WFE of Y and X Polarizations

Polarization-Induced Phase Errors: Differences

450 nm	550 nm	950 nm
0.010 wave RMS	0.002 wave RMS	0.005 wave RMS

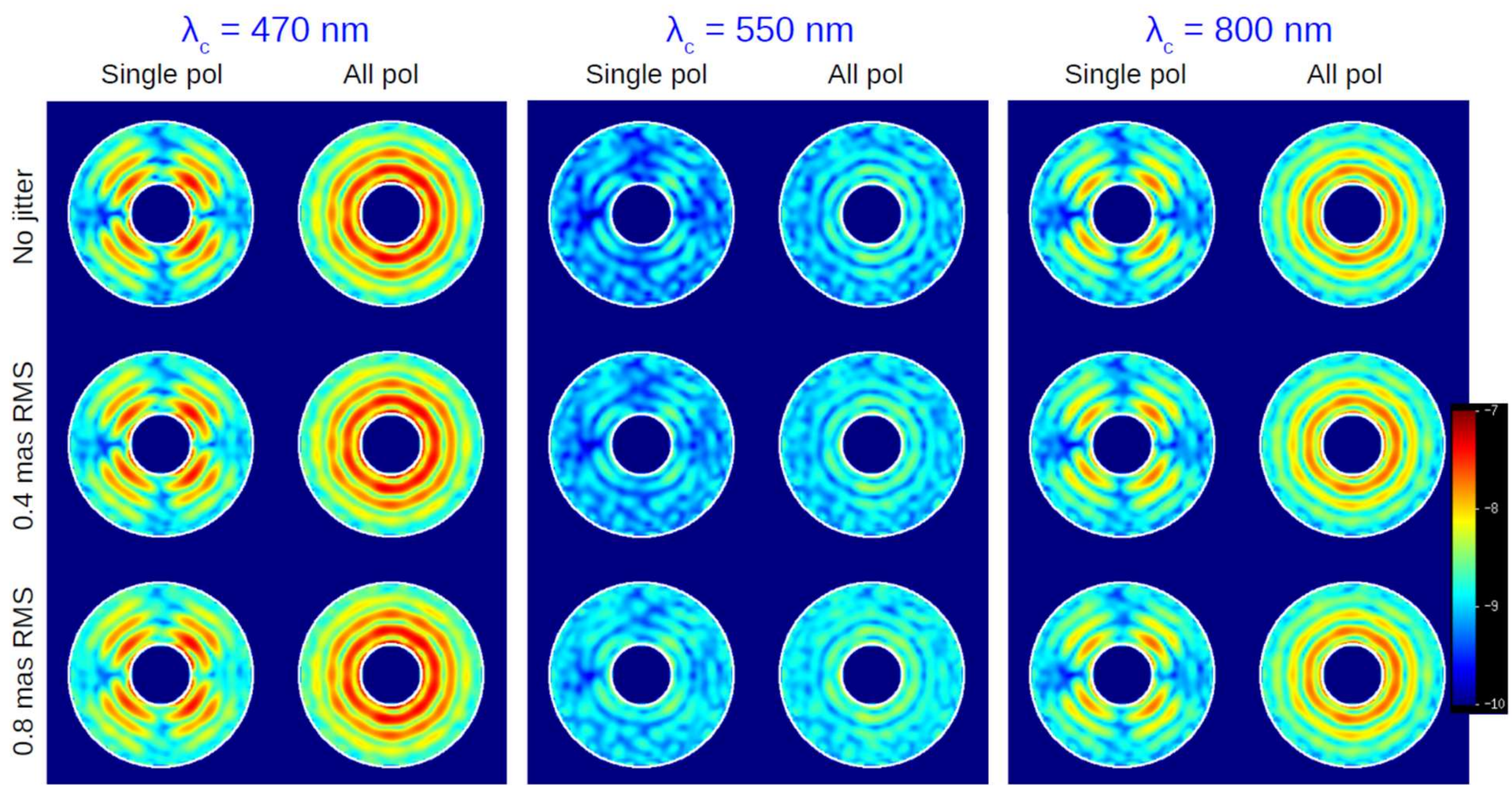
Pol_X - Pol_Y



- Linearly polarized light was input to the telescope at -45° and +45° to represent unpolarized light
- Light from each angle was analyzed with X and Y linear polarizers at the pupil, producing 4 maps: $Pol_{X,-45°}$, $Pol_{X,+45°}$, $Pol_{Y,-45°}$, $Pol_{Y,+45°}$

Effects of Polarization induced WFE

HLC with Polarization, Jitter & 1 mas Star



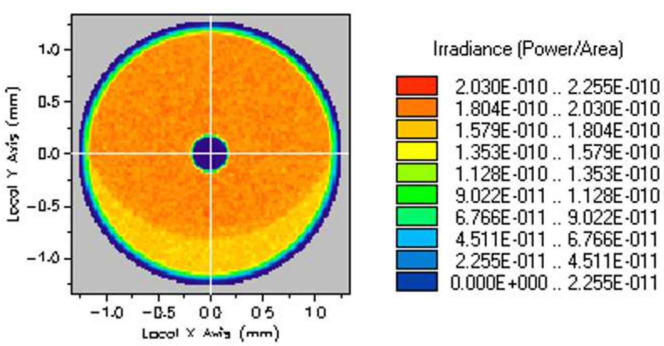
"All pol" mode provides sufficient contrast and ~2x gain in throughput except at 470 nm, so we added an un-polarized imaging mode."

Stray Light Analysis for OMC Testbed

- Single level optical surface scatter is the principal source of stray light for rays with an OPD less than 5.5 um
  - The small opening in the field stop mask means that only scattered rays with propagation directions very near the source specular rays reach the detector.
- Second level scatter events introduce path errors in excess of 5.5 um.

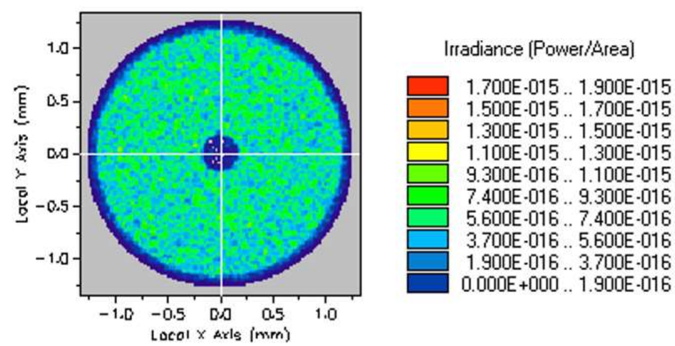
Coherent

|OPD| ≤ 5.5 um
Integrated Flux: 8.35e-9



Incoherent
2.85e-15/0.055 =
5.2e-14

|OPD| > 5.5 um
Integrated Flux: 2.85e-15



Mask/apertures in use:
- Pupil mask, lyot stop mask, occulting disk, field stop aperture
- There are no direct or ghost-only paths to the detector

Analysis conducted by Photon Engineering Inc. under contract with JPL.

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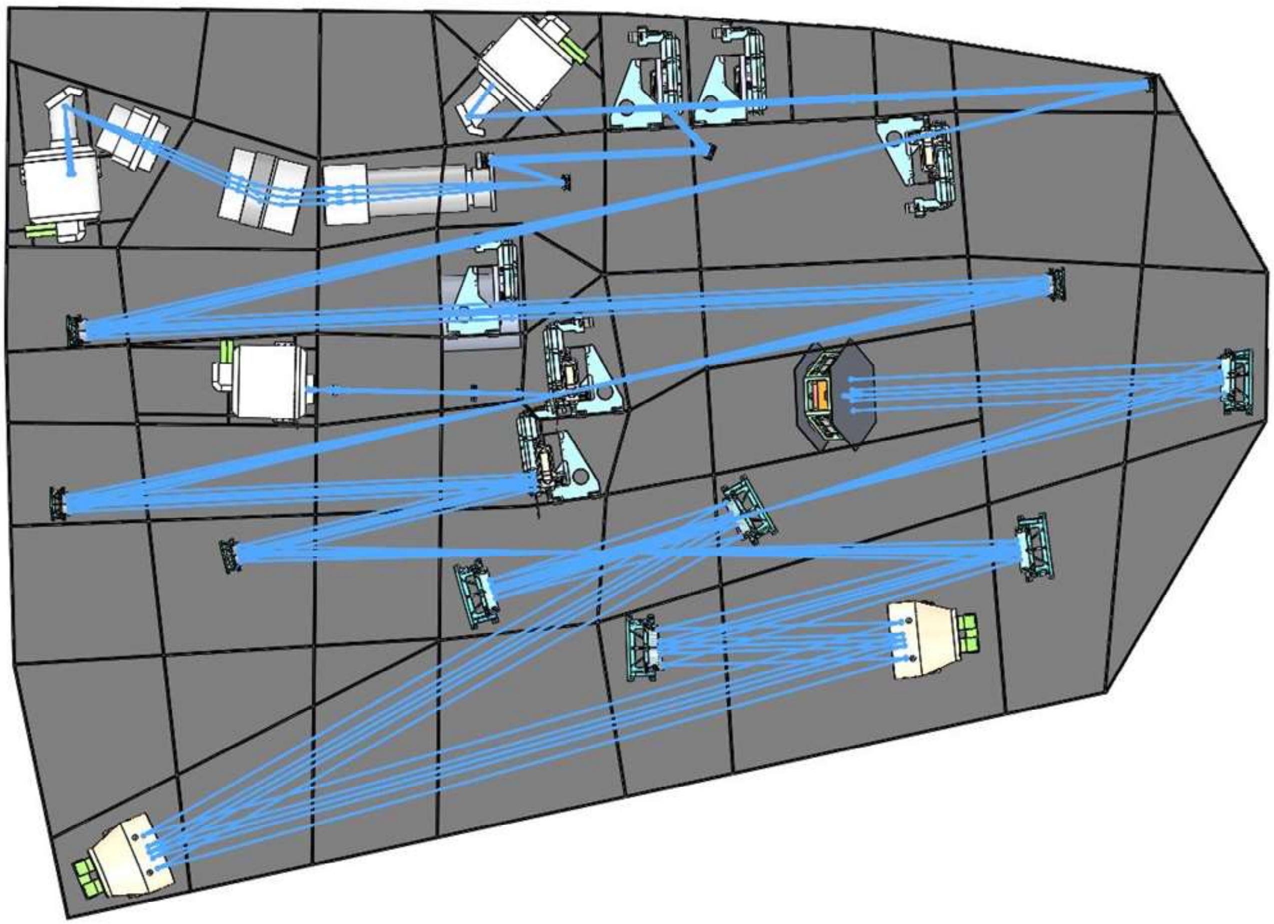
Summary

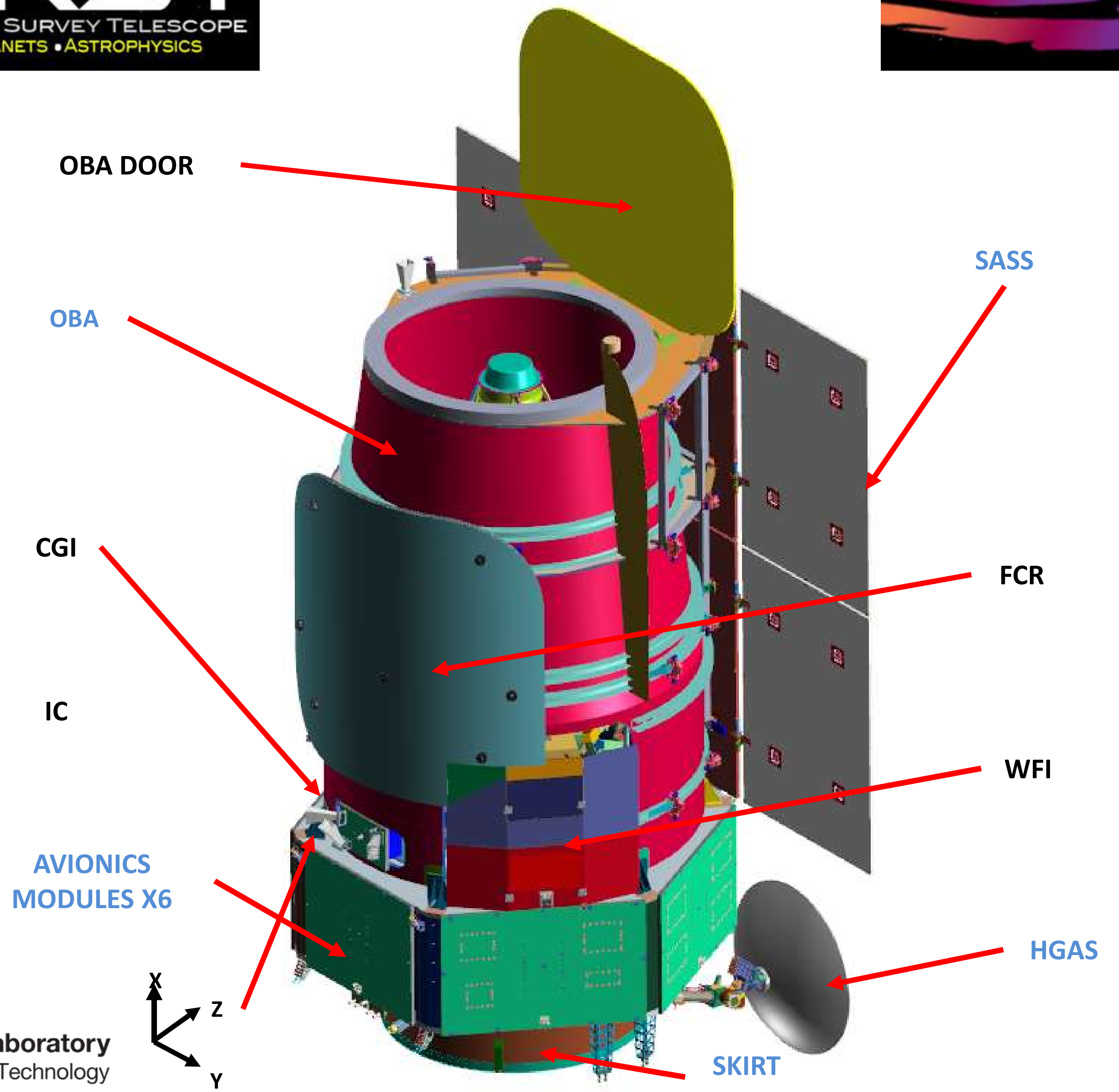
- TCA (POMA + TOMA) attached to AMS for stable interface with OTA
- Conic surfaces for M3 and M4
- Pupil at FSM
- Smaller beam print at FSM
- Only one fold mirror
- Un-polarized imaging of higher throughput
- Four polarized imaging modes
- Stray light from optical surfaces not an issue

- Backup Slides

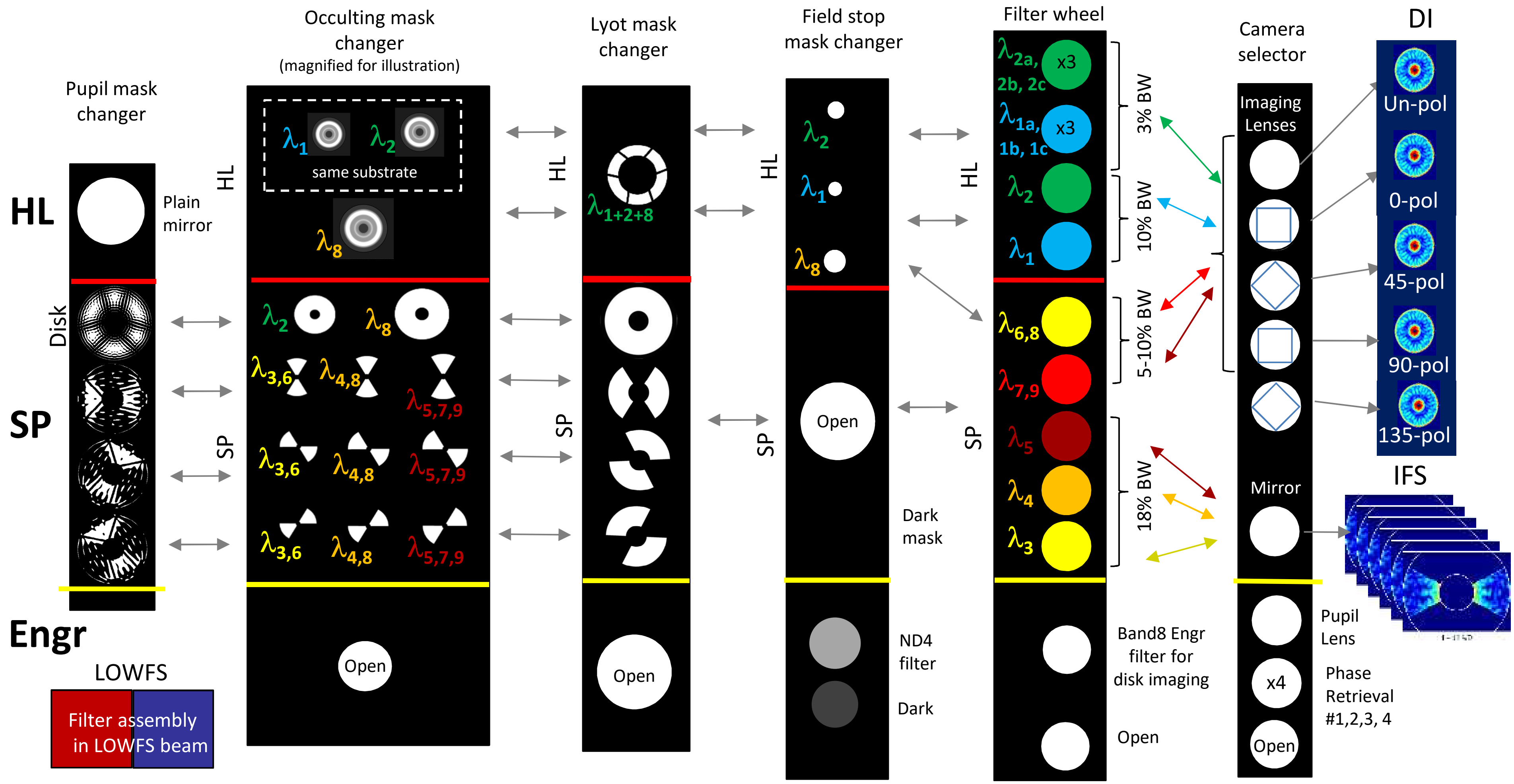
CGI Optical Bench Assembly–Top View



WFIRST Spacecraft Architecture



CGI Filter Wheel Populations

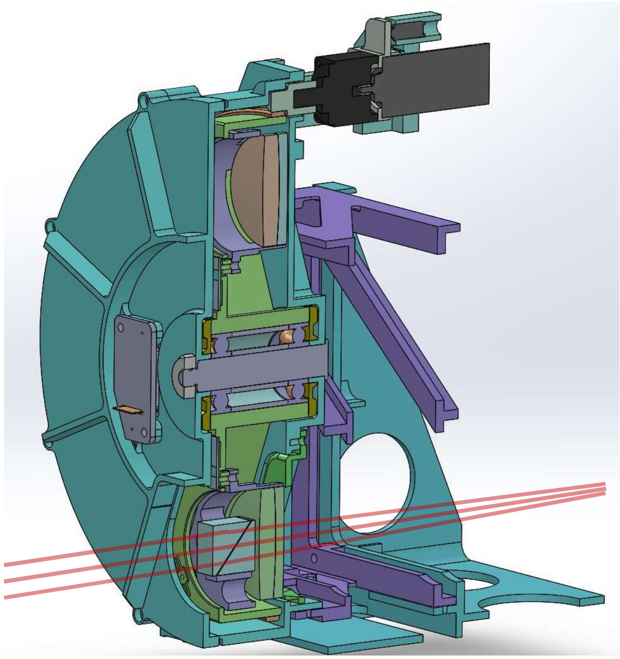


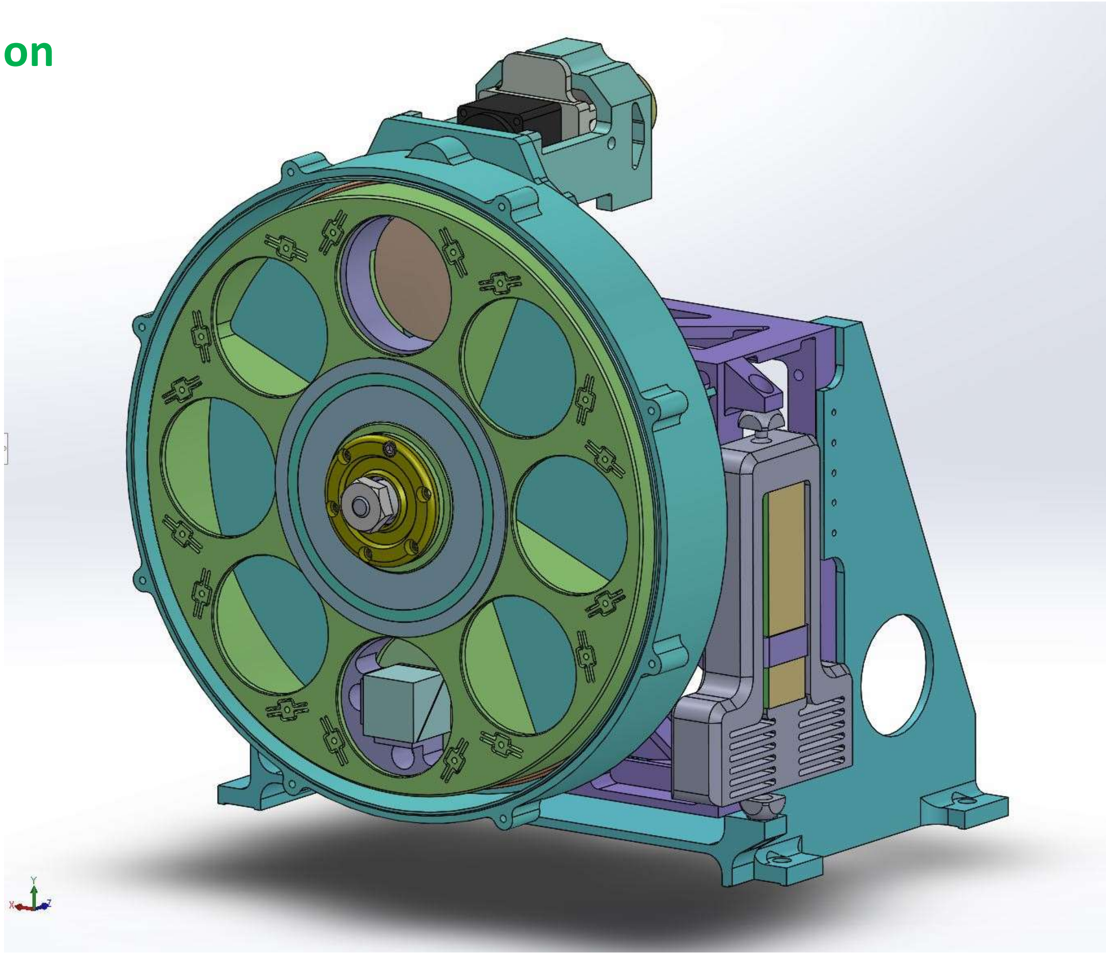
λ_1= 508nm λ_2=575nm λ_3=660nm λ_4=770nm λ_5=890nm

λ_{1a}= 491nm λ_{1c}= 524nm λ_{2a}=555nm λ_{2b}=594nm λ_6=661nm λ_8=721nm λ_7=883nm λ_9=950nm

Polarizer and Lens in Wheel

Polarizer and lens fits in a slot on Camera Select wheel





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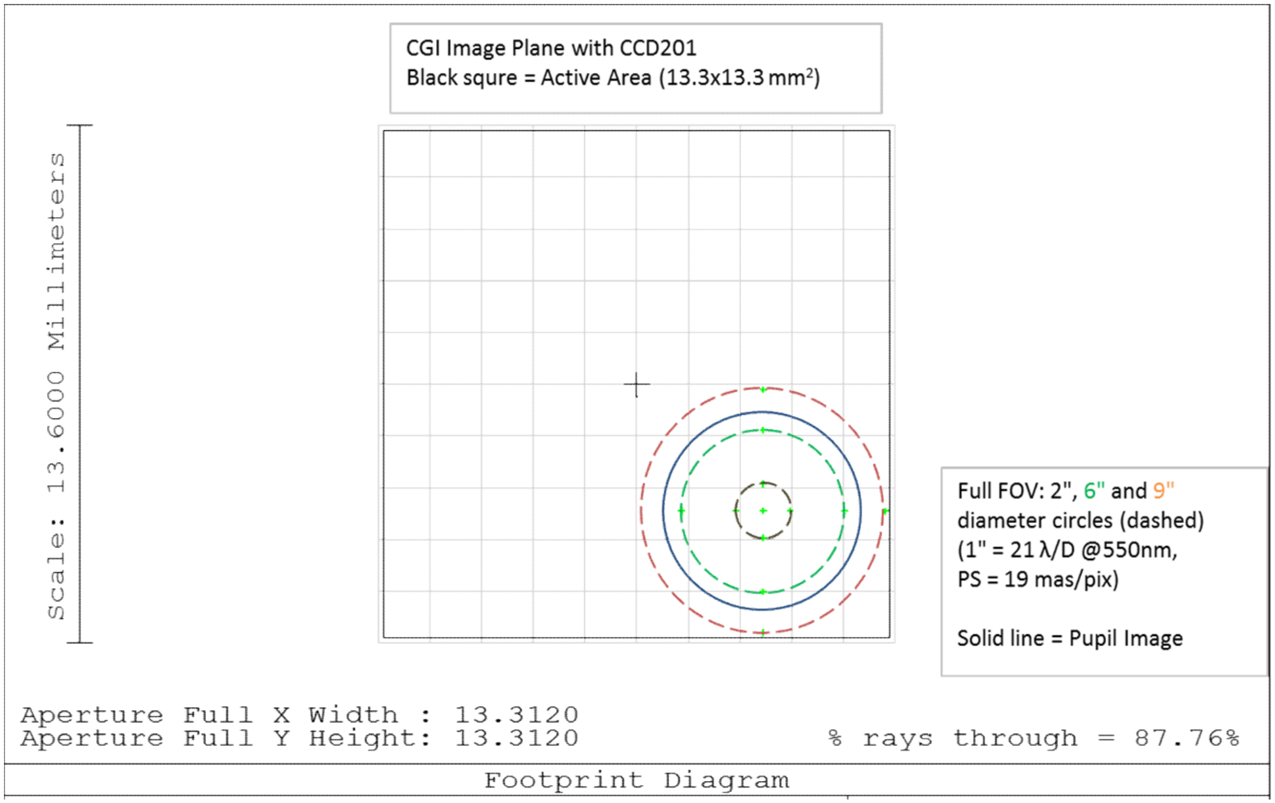
Proposed Placement of Image on CCD



- Image in the quadrant of fewest charge transfers
- Least impacted by traps

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Wavefront Control Modeling

- Electric Field Conjugation was used in these cases, with regularization and using field weights applied. PROPER was used for propagation. The computed wavefronts were used as "measured" wavefronts (i.e., exact knowledge).
- The ***image*** in a single polarization channel is the sum of the ***intensities*** of the -45° and +45° wavefronts in that channel (e.g., $Pol_X = Pol_{X,-45°} + Pol_{X,+45°}$). Without polarization splitting, the image is the sum of intensities from both channels ($Pol_X + Pol_Y$).
- The ***measured wavefront*** in a single polarization channel is the average of the -45° and +45° wavefronts in that channel. Without splitting, it is the average of the wavefronts in both angles in the X and Y channels (four wavefronts in all).
- When running wavefront control (EFC) for one polarization channel (X or Y), the "measured" wavefront is computed using the mean wavefront of the two angles to provide a DM solution that is then evaluated by computing the fields for both angles separately and then adding their intensities together.
- The worst case will be a solution optimized for both X and Y polarizations simultaneously (equivalent to no polarization splitting). The best will be without any polarization errors. The single-channel (X or Y) result will be in-between.